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Special Issue Reprint

Agricultural Food Consumption, Public Policy, and Farm Household Economics

Edited by
Hung-Hao Chang, Pei-An Liao and Jiun-Hao Wang

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This is a reprint of articles from the Special Issue published online in the open access journal *Agriculture* (ISSN 2077-0472) (available at: https://www.mdpi.com/journal/agriculture/special_issues/V71873597D).

For citation purposes, cite each article independently as indicated on the article page online and as indicated below:

Lastname, A.A.; Lastname, B.B. Article Title. *Journal Name* **Year**, *Volume Number*, Page Range.

ISBN 978-3-7258-0883-0 (Hbk)
ISBN 978-3-7258-0884-7 (PDF)
doi.org/10.3390/books978-3-7258-0884-7

Contents

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Review

Exploring the Hype of Blockchain Adoption in Agri-Food Supply Chain: A Systematic Literature Review

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Abstract: This study examines the effect of blockchain adoption on the agri-food supply chain. A systematic literature review approach was used to analyze and synthesize the findings from the existing literature, focusing on fundamental research themes, research gaps, and the direction of future research on the impact of blockchain adoption in the agri-food supply chain. Twenty-seven full-length articles were considered and thematically analyzed in this study. The authors identified eight themes from the literature, including factors responsible for blockchain adoption and new research areas such as digitalization and the impact after adoption. These themes shed light on the agri-food supply chain practices following the adoption of blockchain technology. Moreover, this study provides a foundation for strategic and policy initiatives in the agri-food industry involving blockchain technology. The findings indicate that critical factors driving blockchain technology adoption in the agri-food industry include ensuring food traceability and transparency, food safety and security, food supply and logistics, food integrity, environmental awareness, and reducing food waste. Additionally, this study highlights the importance of guidelines and policy-level involvement after adopting blockchain technology, particularly in facilitating accurate quantification and promoting digitalization to address challenges and streamline processes. The study concludes by suggesting future research avenues for blockchain technology in the supply chain domain.

Keywords: agri-food industry; blockchain technology; supply chain; systematic literature review

Citation: Yogarajan, L.; Masukujjaman, M.; Ali, M.H.; Khalid, N.; Osman, L.H.; Alam, S.S. Exploring the Hype of Blockchain Adoption in Agri-Food Supply Chain: A Systematic Literature Review. *Agriculture* **2023**, *13*, 1173. https://doi.org/10.3390/agriculture13061173

Academic Editors: Hung-Hao Chang, Pei-An Liao and Jiun-Hao Wang

Received: 26 April 2023
Revised: 19 May 2023
Accepted: 23 May 2023
Published: 31 May 2023

1. Introduction

Blockchain technology (BT) is an important topic due to its recent high expansion in modern agriculture. The prominence of BT in the agri-food supply chain (AFSC) ensures transparency, real-time information on any product, fraud circumvention, manipulation resistance, reduced operational costs, audibility, enhanced product quality, safe and healthy consumption, and a more structured certification process [1]. Although blockchain technology appears favorable in several sectors, it is still hard to apply due to its convolution [2]. The awareness of BT is high and it is argued to be easy to use. From the context of the AFSC, there are still obstacles faced by the supply chain members when they start implementing blockchain technology in their operations. For example, Rejeb et al. [3] highlighted significant barriers, such as technical, organizational, and regulatory challenges, that diminish the potential of the AFSC and impede BT adoption. However, BT has been working in other industries, yielding favorable output to adopters [4]. The mixed findings on the impact of BT, especially between agri-food and other industries, indicates the embryonic stage of BT in the agri-food industry [5]; therefore, it warrants further exploration in this context, especially of the impact of BT adoption in the AFSC.

Recently, a large amount of research has emerged regarding blockchain adoption and the food supply chain (FSC). Even within the specialist literature on BT in the AFSC,

this study mainly focuses on application, identification, evaluation, and interpretation. For instance, the literature aims to provide a clear definition, necessary elements, challenges, and drivers of BT among practitioners [2,6]. In short, the literature argues that it is a major challenge to make BT more accessible, as is the case for similar technologies such as the Internet of Things (IoT), big data, radio frequency identification (RFID), robots, sensors, etc. Similarly, in terms of how these technologies can be integrated into BT [7], Ali et al. [5] argued that the compatibility of these technologies with BT is promising; thus, a clear regulatory framework should be developed to ease the process during blockchain adoption and implementation in the AFSC [2]. Following this line of argument, scholars have tried to assimilate the impact of BT adoption to the entire FSC [8]. For instance, Turkey has started implementing blockchain technology in their dairy farms [9]. However, public awareness of such efforts and their featuring of BT is still shallow.

Scholars [3,6] highlighted that the impact of BT adoption on the AFSC is vague, complex, and multifaceted and requires attentiveness from the members of the AFSC such as producers, processors, wholesalers/distributors/suppliers/, retailers, and consumers, including society and policymakers. The complex nature of BT adoption is at the embryonic stage and complex for the AFSC, and the previous literature is yet to provide a holistic understanding of the topic. Therefore, a clear research framework requires development; this study uses a systematic literature review (SLR) to analyze and assimilate extant work carried out on BT in the AFSC [10]. In a nutshell, this study's research questions are summarized as follows:

- RQ1: What is the research profile of the relevant prior literature concerning the impact of implementing BT in the AFSC?
- RQ2: What research themes are related to the issues examined in the existing literature concerning the impact of BT adoption in the AFSC?
- RQ3: What are the research gaps and limitations of the prior literature on BT in the AFSC?
- RQ4: How can future BT researchers in the AFSC expand their research and develop a comprehensive research framework?

Several SLRs are being carried out on BT in the AFSC. For example, Mangla et al. [9] reviewed the societal impact of BT in milk supply chains using the system dynamic technique (Table 1). The research of Rejeb et al. [3] identified potential regulatory, technical, and organizational challenges during BT adoption in the AFSC. Yang et al. [8] discussed the challenges and remedies of BT adoption. In addition, more technical studies are related to the types of BT platforms used for the AFSC to gain coordination mechanisms [11,12]. Several other studies focused on issues related to BT adoption, such as scalability, privacy, incentivization, and regulations [13], and industrial case studies with impacts and challenges have started applying BT in their operations [2,3,9]. Moreover, BT adoption in the AFSC literature is also discussed from different perspectives, such as stakeholder adoption behavior [11], societal impact [9], and performance impact [6]. Thus, this study can provide a more detailed analysis of preceding studies by focusing on the impact of BT adoption and implementation across the AFSC.

Table 1. Existing research on BT in the supply chain.

Sources	Methodology	Findings	Limitations
[6]	Literature overview and exploratory case studies (primary data)	• Blockchain technology platform types (BCTPT) differentiated through coordination mechanism. • Tested performance impact.	The impact of BT on supply chain networks was not addressed.
[11]	Qualitative analysis/ Exploratory research	The normative stakeholder management approach positively impacts the use behavior of BT.	Only used the societal factors of adoption of BT and the contextual factors were ignored.

Table 1. *Cont.*

Sources	Methodology	Findings	Limitations
[12]	SLR/Primary data	• Mapped out how BT has evolved with respect to its usage in the supply chain sector. • Sectoral adoption, types of BT adopted, and the status of an organization adopting successful projects.	Missed out on elaborating on the implementation challenges and their potential mitigation strategies.
[9]	Qualitative study/Case study	• Reviewed the societal impact of BT in milk supply chains using the system dynamic technique. • Explored challenges that have started applying BT in their operations.	Did not use the holistic view. Used only factory (firm) perspective; the end consumer context is missing. Performance analysis using BT in specific supply chain units is also omitted.
[8]	Qualitative studies/ Analytical analysis	• Discussed the values and impact BT had on retailing, suppliers, and consumers during the COVID-19 outbreak. • Pricing, incentives, and required investment for implementation were also addressed.	• Strategies and policies implementing BT were not discussed. • Various modes of BT implementation and involvement were not focused on.
[2]	Literature review	• Showed impacts and challenges that have started applying BT in their operations using industrial case studies.	The mitigation strategies and policies to overcome the challenges were left out.
[3]	Systematic review/ Bibliometric analysis	• Identified potential regulatory, technical, and organizational challenges during BT adoption in the AFSC. • Discussed the constraints that have started applying BT in their operations.	Selected only Scopus literature data and omitted the WOS data based on retrieving articles.
[13]	Quantitative study/ Primary data	Found the effects of data-driven supply chain capabilities (scalability, privacy, incentivization, and regulations) on financial performance.	Did not discuss the adoption factors, and failed to show the holistic view and other nonfinancial impacts.

The topic of the impact of BT adoption in the AFSC is multidisciplinary and interdependent. Moreover, affiliated studies appear in journals with various disciplines and audiences. Thus, the topic remains highly important. The findings and results of the present study can gain interest from a wide range of researchers, policymakers, and practitioners as it is a comprehensive study of the research-driven study literature. Researchers and scholars can gain interest in understanding more about the topic of interest as it has not gained much attention from the research community. Practitioners can use the present study to know more about the impacts of blockchain adoption in the AFSC and prioritize approach fields of action. Likewise, policymakers should undertake the necessary ideas to develop policies concerning the impact of BT adoption in the AFSC. Thus, this SLR significantly contributes to upcoming practices and theories.

This paper is structured as follows. Section 1 outlines the introduction. Section 2 defines the boundaries of the review. Section 3 focuses on methodology and research profiling. Section 4 presents the thematic foci. Section 5 exhibits research gaps and directions

for future research. Section 6 focuses on the development of the framework. Section 6 configures the conclusion, implications, and limitations, with recommendations for future SLRs.

2. Status of AFSC Research and Scope of This Review

The agriculture industry has been in the foreground of exploring BT since its introduction as a favorable technology that may benefit the supply chain. The AFSC has diverged from other types of supply chains since it deals with more crucial issues such as interactions with supply chain members, commodities of a perishable nature, and inter-sectoral influence from farm to fork [5]. The crisis connected with the AFSC involves its transparency, visibility, sustainability, safety, efficiency, and the quality of the processes [14]. Researchers have confirmed that the AFSC relates globally to relevant stages, including farm production, storage and handling, processing, retailing, and consuming [15]. Inefficiencies in the AFSC, such as the complexity of goods exchange, high-risk development between buyers and sellers during exchange value, logistics expenses, and issues tracing the environmental footprint and product origin, are among the potential areas to which BT could provide a solution [7]. Previous studies contend that the initial stages of FSC contribute the utmost towards BT adoption [7]. Initially, BT was adopted in the AFSC due to its four main benefits, which are "information transparency", "food traceability", "recall efficiency", and "efficiency after IoT combination" [16]. A previous study has contended that BT adoption has contributed significantly to the AFSC industry [8]. This, however, has been contested in BT literature, which suggests that poor handling still exists after the technology's adoption (i.e., in Africa [2], China [17], and Turkey [9]), mainly due to the complexity of the blockchain system itself.

Understanding the impacts brought by BT adoption is difficult as it involves several peripheral impacts. The prior literature suggests that although blockchain implementation has provided various benefits, it still has drawbacks after implementation [3] (Table 1). Scoping the BT adoption concept and extending the suggestion of Kamilaris et al. [7], Rogers and Ban, and [18,19], the present study illustrates the five adoption stages of blockchain technology that connect the scope of BT applications in AFSC operations among the members of the AFSC.

The first stage is based on laggards, which represent the producer of the AFSC. Farmers are usually the producers of the AFSC. Farmers are known as laggards in blockchain adoption because they are unfamiliar with BT, comfortable with traditional methods, and lack knowledge and skills in BT [2]. Farmers oversee seeding, fertilizing, crop cultivation, checking weather conditions, and caring for animal and plant welfare [7]. All this information requires storage in the blockchain, which is difficult as they are not used to the system [2]. Mostly, farmers in rural areas should be informed and taught about innovation [19].

The second stage is based on the late majority, representing the processor as the processing stage is more concerned with transforming the primary product into secondary products. It involves packaging, which provides all relevant information such as processing procedure information about the raw materials used in the product. The processors decide to implement [7] the innovation by looking at the development of its adoption among other members of the AFSC [19].

The third stage is based on the early majority, representing the distributor—the third member of the AFSC. Distributors are usually responsible for taking care of the product and storage conditions such as temperature and humidity while providing shipping details and time in transit at each transport used to deliver the product [7]. The distributor is categorized as the rare leader, whereby they adopt BT after acknowledging its adoption by other members of the AFSC. They are also the decision makers who decide on implementing the innovation [19].

The fourth stage is based on the early adopters. Early adopters represent the retailer, the fourth member of the AFSC. Retailers usually provide all the information consumers need (expiry dates, product quality, product origin, storage conditions, and time spent on

the shelf) on the package [7]. Retailers are known as early adopters as they are the opinion leaders in the chain. They are aware of the changes and demands from the consumer that lead them to adopt changes, including adding blockchain features at the retailing level. Retailers are the members of the AFSC that implement the innovation to provide all relevant information to the consumer [19,20].

The final stage represents the consumers, who are the innovators that are willing to learn and take risks to accept and develop new ideas. Consumers usually connect to the internet through mobile phones to scan quick response (QR) codes for detailed information about the product's origin [7]. In the AFSC, the consumers are linked as the innovators as the consumers are the final supply chain members that demand transparency and traceability about the product's origin. Thus, consumers are the first party to adopt blockchain features to obtain all the relevant information and can confirm whether the technology can be assumed [19].

To this end, the current study only emphasizes the motive to adopt blockchain technology and the stages involved for generic AFSC members. As discussed above, blockchain adoption focuses on the five steps of time constructed in the diffusion of innovation theory, which are knowledge, persuasion, decision, implementation, and confirmation, by explaining the information collected and stored in the blockchain under each member of the AFSC (i.e., producers, processors, distributors, retailers, and consumers), respectively.

3. Methodology

This study intends to use the SLR methodology, focusing on a well-defined and well-planned protocol. SLR development consists of two phases. The first phase includes keyword (as presented in Table 2) search and execution of documents search using the Web of Science database, including the inclusion and exclusion criteria (as presented in Table 3) of database search [21]. The second phase presents and discusses the findings from the results of SLR.

Table 2. Keywords for literature research.

BT Adoption-Related Keywords	AFSC-Related Keyword	Search String
Blockchain adoption Blockchain implementation Blockchain adoption impact Blockchain implementation impact	Food supply chain Agriculture Agri-food supply chain Supply chain	"Blockchain adoption impact in AFSC" or "Blockchain implementation impact in AFSC" or "Blockchain adoption impact in agriculture" or "Blockchain implementation impact on Food Supply Chain"

Table 3. Study inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Articles published in English from the year 2018 to the year 2022; Articles focusing on aftermath of BT adoption and implementation in AFSC; Peer-reviewed articles; Articles focusing only on aftermath of BT adoption in AFSC or FSC only.	Studies on blockchain implementation in other than AFSC or FSC industries; Proceedings papers, book chapters; Articles written other than in the English language; Duplicated articles.

3.1. Review Planning

The authors of this study selected the Web of Science database after setting initial keywords to search relevant studies related to the impact of blockchain adoption in AFSC. The search was continued by selecting leading journals in agriculture, food supply chain, food, and blockchain adoption to ensure the chosen keywords were all-inclusive. A review panel was established to provide the profiling and rigorous selection of articles. Developing a review panel to set conceptual boundaries for a review is essential. Three experts were included as the review panel members (two professors and one researcher).

This panel debated, agreeing on selected keywords to prepare the final list. This study used two primary databases, Web of Science and Scopus, in line with Derwik et al. [22].

3.2. Specifications of the Study

The inclusion and exclusion criteria were applied in Table 3 to obtain the study specifications using a database search. The central inclusion criteria of articles were publication between 2018 and 2022 and only in the English language. We did not consider articles in other languages. We only considered articles that are only peer-reviewed and focus on BT in AFSC (limited to our themes only). We only considered published full-text articles and excluded proceedings papers, book chapters, and duplicated articles.

3.3. Data Extraction

Boolean logic was applied by selecting the keywords from the final list and rebuilding them into a search string by applying the "Or" and "And" connectors. Using the transformed search string, the authors searched for journal titles, abstracts, and keywords using the WOS database. The search focused on articles published from 2017 to November 2022. The study of Vadgama, & Tasca [12] stated that the peak time of blockchain projects being created was in 2018, and 35% of the market-ready projects were intended to be implemented in 2017. The authors found 112 articles related to the impact of adopting BT in AFSC. From this list, 25 duplicated articles were removed from the database. Then the authors continued by removing all proceedings papers, followed by articles not published in English. The next step was applied using inclusion and exclusion criteria, which reduced the total number of articles in the dataset to 87.

To verify the articles' input in more detail, the review panel screened them thoroughly using an Excel sheet and finalized the articles by reviewing the titles, abstracts, and keywords. To ensure a vigorous screening protocol, each panel screened the Excel sheet individually and discussed the articles that were short-listed individually by each panel to come up with a final agreement. From the discussion, 46 articles were removed as the panels found them to meander from the conceptual boundaries and scope. The researchers conducted forward and backward chaining citations for each article to ensure vigorous screening protocol and reduce the chances of missing relevant articles. Fourteen articles were detected from the chaining citation, including proceedings papers. After a complete screening set, 27 full-length articles were finalized (Figure 1). The following parts of SLR comprise the data execution process by discussing the results of research profiling and content analysis.

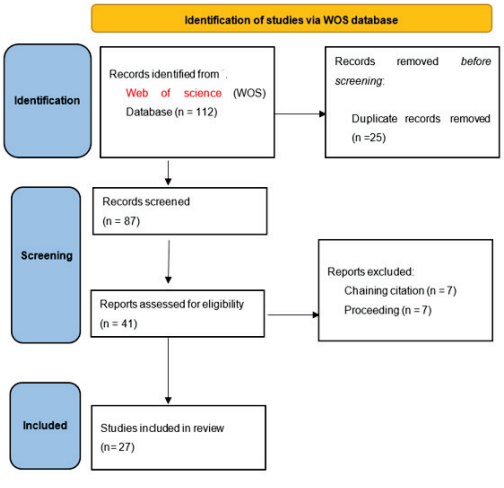

Figure 1. Schematic view of the stages and their criteria.

3.4. Data Execution: Research Profiling

This study, using research profiling, suggests that the literature about the impact of blockchain adoption is relatively new, as the number of publications started increasing in 2018. The most productive authors are depicted in Figure 2. Focusing on the study design, most studies were qualitative—68%, as shown in Figure 3. This is an apparent result since a significant amount of literature is focused on ex ante and ex post of blockchain adoption and comprises an analysis using primary and secondary data.

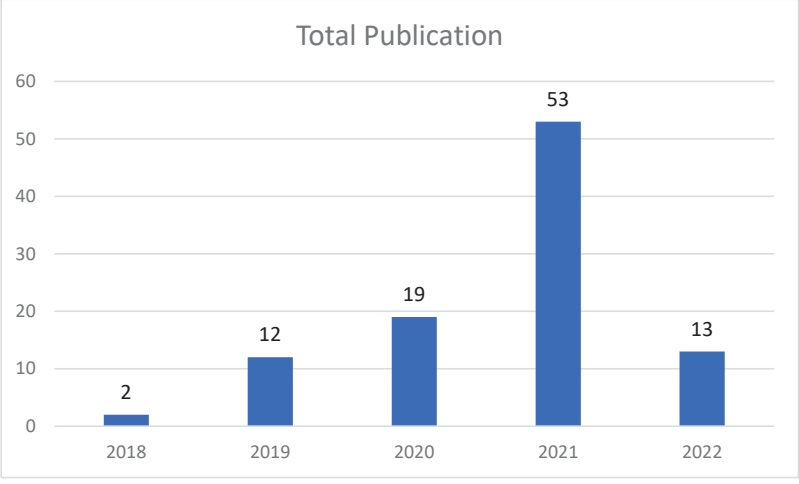

Figure 2. Year-wise publications.

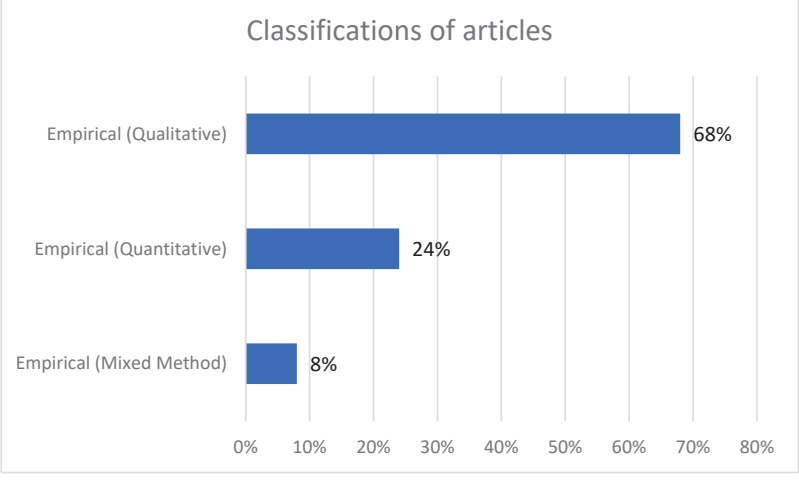

Figure 3. Classifications of articles.

4. Thematic Foci

Providing deep and comprehensive insights from the existing literature to improve our understanding towards the impact of blockchain adoption in the AFSC was the objective of the review. Thus, a few researchers developed themes separately. After insightful discussions, they finalized seven broad themes. Other themes were clustered into eight, focusing on different elements from blockchain adoption in the AFSC. The themes are illustrated in Figure 4.

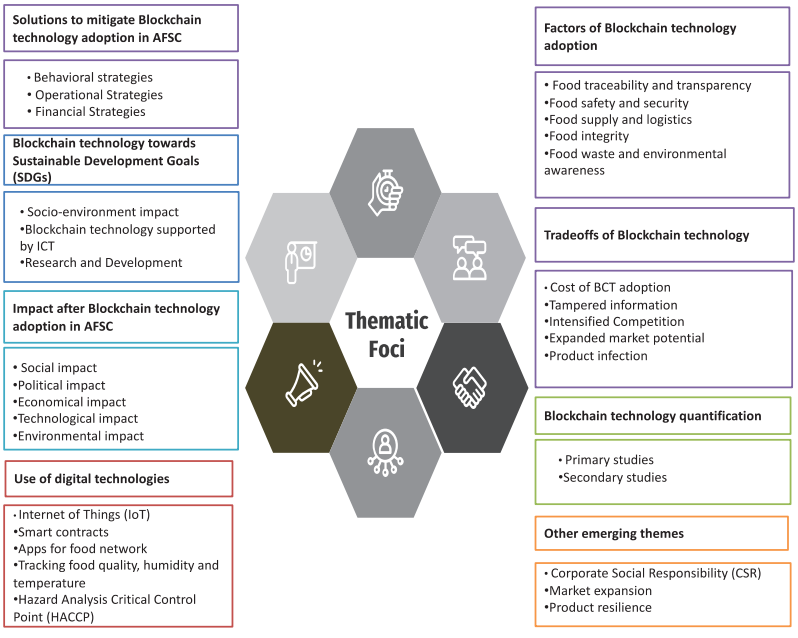

Figure 4. The selected themes of this study.

4.1. Factors of Blockchain Adoption

Adopting BT is crucial for business success, particularly for the supply chain industry. Scholars have optimized aspects such as the compatibility between the organizational need and the BT specification, the interoperability of technology within multiple systems, and the adopters' technology maturity level, which are crucial to avoiding misalignment of rationality and the reality of needs [16,23–25].

Analyzing factors that cause blockchain technology adoption is of topical interest in the extant studies. The extant literature that focuses on the factors responsible for BT criteria generation is divisible into particular streams, such as the stream of literature that deals with enlisting many factors that lead to high blockchain technology adoption generation in the AFSC [7,16,23–25]. Furthermore, during this review, we compared the selected 27 articles thoroughly and classified the factors which appear repetitively in the literature as predictors of BT adoptions. Some of the major sources of blockchain technology, as these studies indicate, include food traceability and transparency, food safety and security, food supply and logistics, food integrity, and food waste and environmental awareness, which can encourage blockchain technology adoption in the AFSC (Table 4), and are discussed as follows:

Table 4. Summary of the key aspects based on thematic foci [6–9,11,12,16,17,23–43].

No	Themes	Subthemes	Explanation	References
1.	Factors of blockchain adoption	Food traceability and transparency	Ensuring data availability, enhancing security measures, enforcing immutability.	[7,23,24,32]
		Food safety and security	Detect and prevent food contamination and food fraud using blockchain technology.	[6,23,30,32]
		Food supply and logistics	Processes and systems involved in the production, distribution, and management of food from its source to the consumers.	[24,31,33]
		Food integrity	Ensuring trust in food exchange activity.	[7,34]
		Food waste and environmental awareness	Ensuring waste reduction through the food management process.	[7,26,35]

Table 4. *Cont.*

No	Themes	Subthemes	Explanation	References
2.	Impact of blockchain adoption in agri-food supply chain (AFSC)	Social impact	Influence that an individual, organization, or initiative has on society or specific communities.	[9,24,28]
		Political impact	Influence and consequences that political decisions, actions, or events have on individuals, communities, societies, and governance systems.	[2,12]
		Economic impact	Consequences and effects that economic activities, policies, or events have on the economy of a country, region, or community.	[8,17,24]
		Technological impact	Effects and consequences of technological advancements, innovations, and the widespread use of technology on individuals, societies, and various sectors of the economy.	[2,8,28]
		Environmental impact	Effects and consequences of human activities on the natural environment and ecosystems.	[36]
3.	Blockchain quantification	Primary studies	Primary research, or original research, refers to research studies conducted by researchers or individuals to gather new data or information firsthand.	[27,37,38]
		Secondary studies	Secondary research studies, or literature reviews, involve the synthesis and analysis of existing research and data from primary studies conducted by other researchers.	[16,28,29]
4.	Trade-offs with blockchain technology adoption in agri-food supply chain (AFSC)	Cost of blockchain technology adoption	Blockchain technology streamlines processes, reduces paperwork, and automates transactions through smart contracts. These efficiency gains can result in cost reductions, enabling companies to offer products or services at lower prices.	[8,17]
		Tampered-with information	BT, by design, is resistant to tampering and manipulation of information. The decentralized and distributed nature of blockchain, coupled with its cryptographic algorithms and consensus mechanisms, makes it extremely difficult for malicious actors to tamper with data recorded on the blockchain.	[8]
		Intensified competition	BT enables direct peer-to-peer transactions without the need for intermediaries, such as banks, payment processors, or centralized marketplaces. This disintermediation reduces barriers to entry and allows new players to enter the market, challenging traditional incumbents.	[17]
		Expanded market potential	Startups and entrepreneurs can leverage blockchain's capabilities to develop novel business models, disrupting traditional industries and challenging incumbents.	[17]
		Product infection	Blockchain technology can be used to verify the authenticity of products and components. Each item can be assigned a unique identifier or digital signature recorded on the blockchain, ensuring that counterfeit or infected products can be easily identified.	[8,17]

Table 4. *Cont.*

No	Themes	Subthemes	Explanation	References
5.	Use of digital technologies	Internet of Things (IoT)	By integrating blockchain technology with IoT devices, sensors, and other data sources, it becomes possible to track the entire journey of a product from its origin to the end consumer. This enables quick identification of the source of infection or contamination, allowing for targeted recalls and minimizing the impact on consumers.	[7,32]
		Smart contracts	Blockchain technology provides the underlying infrastructure for secure and transparent data storage and transfer, while smart contracts enable the automation and execution of predefined rules and agreements on the blockchain. Together, they offer new possibilities for building decentralized and efficient systems across various industries.	[30]
		Apps for food network	Blockchain can enable end-to-end traceability in the food supply chain, from the farm to the consumer's table. By recording each transaction and movement of food products on the blockchain, stakeholders can easily track and verify the origin, quality, and handling of the food.	[39]
		Tracking food quality, humidity, and temperature	Blockchain-based apps can facilitate direct communication between consumers and food producers including tracking food quality, humidity, and temperature.	[32]
		Hazards analysis critical control point (HACCP)	Blockchain's immutability ensures that once data are recorded on the blockchain, they cannot be altered or tampered with. This feature helps maintain the integrity of HACCP records, making them trustworthy and reliable for audits, investigations, and compliance purposes.	[7,32]
6.	Solution to mitigate challenges after blockchain technology adoption	Behavioral strategies	Conscious actions and approaches are taken by individuals or organizations to influence or modify human adoption behavior.	[11,31]
		Operational strategies	Plans and methods are implemented by organizations to optimize their operations and achieve their objectives efficiently.	[6,26,28]
		Financial strategies	Deliberate plans and actions undertaken by individuals or organizations to manage their financial resources and achieve specific financial goals.	[25,30,36]
7.	Blockchain technology towards Sustainable Development Goals	Socioenvironmental impact	Blockchain enables transparent and traceable supply chains, allowing consumers and stakeholders to verify the origin, authenticity, and sustainability of products. This transparency promotes ethical sourcing, fair trade practices, and environmentally responsible production.	[29,36,40]
		Blockchain technology supported by information and communication technology (ICT)	Both blockchain technology and ICT share the goal of decentralizing systems and reducing dependencies on central authorities. ICT, through networking and communication technologies, enables the decentralized exchange and sharing of information.	[24,29,36]
		Research and development	Blockchain technology can ensure the integrity and traceability of research data by providing an immutable and transparent ledger. Research findings, experimental results, and data can be recorded on the blockchain, making them tamper-proof and auditable.	[9,24]

Table 4. *Cont.*

No	Themes	Subthemes	Explanation	References
8.	Other emerging themes	Corporate social responsibility (CSR)	Blockchain technology can improve transparency and accountability in charitable donations.	[6,41,42]
		Market expansion	Blockchain technology can enable decentralized marketplaces that connect buyers and sellers from around the world without the need for intermediaries.	[9,17,43]
		Product resilience	Blockchain technology enables end-to-end traceability of products, allowing businesses and consumers to track and verify each stage of the agri-food supply chain (AFSC).	[16,24,43]

4.1.1. Food Traceability and Transparency

The first category focuses on food traceability and transparency which connects the producer who provides all the information about the product's origin, such as raw materials (seeds, fertilizers, feeds, and animal breeds) [7]. Researchers [25,26] admitted that BT offers trackability and transparency in the food supply chain, and stakeholders choose the system accordingly. Dehghani et al. [27] discovered that adopting BT is mainly driven by performance expectancy (PE), transparency, and traceability. These factors have a significant positive impact on the decision of organizations to adopt BT. In other words, organizations are more likely to adopt BT if they perceive it will improve their performance, provide transparency, and enhance traceability.

Ghode et al. and Adamashvili et al. [25,28] argued that BT is valuable for establishing traceability systems and safeguarding production against fraud and contamination. They emphasize that the ability to trace products from the supplier to the end consumer is crucial for ensuring consumers' health and saving lives, which can significantly impact the success of affected businesses. Using a traceability system is beneficial for products with a higher risk of contamination, such as medicine, dairy, and meat [16]. When the risk of contamination is elevated, a traceability system ensures transparency in the production and operational processes [29]. Tsolakis et al. [24] concluded that BT could enable a reliable traceability system in end-to-end supply networks by sharing critical data among all actors involved in the Thailand fish industry. For instance, upstream suppliers can enhance their relationships with corporate customers, increasing business opportunities. Meanwhile, downstream customers can access reliable data that help prevent fraud and ensure food safety, which provides transparency, leading to business growth in local fish industries and the population's welfare. Pranto et al. [30] and Stranieri et al. [31] claimed that implementing BT can provide various benefits, including ensuring data availability, enhancing security measures, enforcing immutability to prevent data tampering, and promoting trust among both producers and consumers.

4.1.2. Food Safety and Security

The second category is food safety and security, which connects to the processors who take responsibility for food packaging to provide the product information, including the list of raw materials used via the coding process on the package [7]. Food safety refers to handling, processing, and hygienically storing food to prevent illnesses in the human population. The use of BT could offer a practical solution to address the pressing need for improved traceability and transparency in ensuring the safety of food products. A number of scholars [23,32] affirm that BT will enhance the safety and security for which it is used in the food supply chain. Through the use of blockchain technology, data manipulation can be prevented, thereby ensuring security. This gives consumers complete confidence in the origin and distribution history of products, while farmers can also access the storage history of seeds [30]. Additionally, governing bodies can use these data to regulate the market. The IoT monitors the entire system, and the blockchain guarantees absolute security [30].

Kramer et al. [6] found that food safety concerns are a significant factor driving the adoption of BT in the agri-food industry. The ability of blockchain technology to detect and prevent contamination or food fraud in the supply chain and facilitate rapid product recalls has led to increased implementation of blockchain projects in the agri-food sector [32].

4.1.3. Food Supply and Logistics

The third category is food supply and logistics, which connects to the distributor. Once the packaging and the coding process are completed, the product is prepared for distribution. Distribution is performed once the delivery time has been set within a certain period, as there might be a storage step for the product [7]. Furthermore, BT leverages total quality management efforts. BT can enable real-time supply network capabilities such as visibility and data-enabled product quality reporting in the fishing industry, enhancing network performance and competitiveness [33]. Tsolakis et al. [24] stated that integrating additional sensors and automation in the blockchain can inspire total quality management to incorporate devices' certification and calibration. Likewise, the research by Stranieri et al. [31] expressed a positive view towards BT, noting that it can enhance extrinsic food quality attributes and facilitate improved information management across food chains. This is attributed to the improved accessibility, availability, and sharing of information enabled by BT. Finally, Dehghani et al. [27] admitted that standardization predicts BT adoption decisions strongly.

4.1.4. Food Integrity

To ensure food integrity, retailers play an essential role by providing the correct information to the customer. For example, Carrefour, one of the famous retailers in Europe, verifies standards and origin traceability in various categories such as dairy products, fish, meat, fruits, and vegetables [44]. The concept of food integrity revolves around ensuring a trustworthy exchange of food within the supply chain, where all actors are responsible for providing comprehensive information regarding the origin of goods, as stated by Kamilaris et al. [7]. In addition, BT is being evaluated for its potential to track the production of nonedible crops, which are susceptible to integrity concerns due to regulatory and legal considerations [7]. The quick and efficient traceability system provided by BT has the potential to identify unethical suppliers, unfair labor practices, and counterfeit products in the wine food chain, indicating a promising future for this technology [34]. Adamashvili et al. [28] proposed that implementing BT necessitates various stakeholders' participation throughout the supply chain. These stakeholders engage in peer-to-peer transactions, enhance accountability, reduce corruption, and generate value for firms and local communities. Furthermore, BT can promote ethical issues such as fair trade and animal welfare through inclusive development, ensuring small producers' access to better markets and secure payment or financing opportunities, as illustrated by FairFood and AgriLedger. Several studies, including those of Bhat et al., Kayikci et al., and Luzzani et al. [23,32,34], pointed out that BT enhances the trust between suppliers and consumers upon proper use.

4.1.5. Food Waste and Environmental Awareness

The fifth category ensures food waste and environmental awareness, whereby the consumers who are the end users of the chain, who buy and demand traceable information, need to acknowledge waste management. For instance, a global recycling venture known as Plastic Bank [45] founded a recycling program in Canada to reduce plastic waste, which is to be applied as well in developing countries [7]. This strategy eventually rewards the public via digital blockchain tokens for whoever brings plastic rubbish to recycling centers [35]. BT offers advantages to various stakeholders involved in the agri-food system, specifically in the global cocoa supply chain. Its implementation can enhance supply chain performance by reducing food loss and waste. Kayikci et al. and Luzzani et al. [32,34] commented that the increased transparency and traceability allowed by BT could ensure waste reduction through the production process.

4.2. Impact of BT Adoption in AFSC

4.2.1. Social Impact

Looking at social impact, Mangla et al. [9] analyzed a dairy farm in Turkey on how BT implementation has impacted the dairy farm's farmers and found that BT has provided many benefits to the dairy farm. Among the benefits brought by BT to society are the following: (1) reducing food fraud, (2) improving the welfare of animals, (3) increasing food security, and (4) providing transparency to the customers. The benefits acclaimed for spurring the social impact are not eminent because the public is unaware of BT's implementation and features. On a similar note, Mangla et al. [9] suggested improving public awareness through educating people on the elements of the blockchain to avoid them from getting trapped in food fraud. Even with the hype of the impact brought by BT towards society, there is a high possibility of specific organizations and suppliers adopting BT cutting corners by not providing accurate information in the system. Suppliers who source their products from unsafe channels tend to tamper with such details before adding them to the BT system [8]. Such behavior has led towards trust issues among members in the supply chain that impede the adoption of BT, hence resulting in swaying away from the primary goal of adoption.

The adoption of BT has significant social implications, including creating new business models, reorganizing existing models, and introducing new systems and skill sets [24,28]. Adamashvili et al. [28] suggested adopting BT requires multiple stakeholders along the supply chain who engage in peer-to-peer transactions, reduce corruption, increase accountability, and create value for firms' local communities. They also pointed out that adopting BT can promote ethical issues such as fair trade and animal welfare through inclusive development that ensures small producers' access to better markets and safe payment or financing opportunities, as exemplified by FairFood and AgriLedger. According to [24], BT can establish end-to-end supply networks in the Thai fish industry, allowing upstream and downstream suppliers to enhance their trustworthy relationships with corporate and downstream customers to leverage the welfare of the local population through increased transparency.

4.2.2. Economic Impact

Niu et al. [17] have stated that BT adoption is expensive, so they have to develop a few solutions, such as increasing the procurement price and improving e-tailing as an option. On the other hand, Yang et al. [8] have justified that the blockchain cannot support cost-sharing contracts and revenue sharing in supply chain coordination during blockchain adoption. The Adoption of the blockchain causes incentive conflict between local and overseas suppliers due to a higher procurement price that affects the market share and profit margin due to the high cost of blockchain adoption [17]. This can directly affect the food supply and logistics industry. The study of Tsolakis et al. [24] contended that using cryptographic proofs to verify the provenance and handling condition of fish can potentially disrupt the food certification industry by reducing the costs associated with audits and certifications. Although Luzzani et al. [34] identified no evidence of the use of BT in agri-food to monitor and reduce energy consumption, they further claimed that the use of BT facilitates increased transparency and traceability and results in reductions in cost in the supply chain. According to Stranieri et al. [31], adopting BT has resulted in economic benefits in terms of profits and/or returns on investment (ROIs). Specifically, the study found that an increase in profits can be observed at the supply chain level for the poultry and orange supply chains, which experienced a significant boost in sales. Additionally, the study revealed that the lemon supply chain improved ROIs, which was attributed to better production cost management, including reduced product loss and improved warehouse management. As per Ghode et al. [25], integrating BT in supply chain operations can minimize transaction costs compared with the conventional supply chain. This can be achieved by accurately forecasting demand, efficiently managing resources, and lowering inventory carrying costs.

4.2.3. Political Impact

The political impact focuses mainly on the government and policymakers relying more on product traceability and the transparency of agricultural processes in developing policies related to BT and the AFSC. Still, most blockchain implementation in the AFSC prioritizes these two terms [2]. Government projects have more complications than those of the private sectors in developing the right blockchain policies due to the bureaucratic system [12]. Thus, the government cannot establish proper policy regulations to achieve food integrity in the AFSC.

4.2.4. Technological Impact

Focusing on technological impact, the blockchain is the latest developed technology already being implemented in the agriculture industry. However, BT is not an accessible technology to be learnt in a short period due to the complexity of the system, meaning that farmers who are unfamiliar with the system cannot utilize it as they do not have much of the knowledge and skills needed to use the blockchain system [2]. It is also known that whatever information is uploaded to the blockchain system cannot be corrected [8]. Not selecting the right BT platform does not uniformly support supply chain management's strategic network control mechanisms [6]. Thus, food transparency and traceability have not been 100% achieved due to the technological impact and challenges supply chain members face. Adamashvili et al. [28] argued that the transparency of BT and its ability to track products throughout the entire supply chain provide an opportunity to identify contaminated products on time, allowing for the recall of only the hazardous items, rather than halting the whole production process. This approach reduces food waste and decreases transportation needs and the associated use of natural resources, which can significantly impact the environment. Tsolakis et al. [24] commented that by integrating all stakeholders, data, and technologies collaboratively, BT could facilitate comprehensive supply chain evaluation and consistently promote environmental sustainability. When integrated into wine sustainability certifications, programs, or standards, BT is also considered a tool for monitoring greenhouse gas emissions and water management [34].

4.2.5. Environmental Impact

BT's adoption by the program of ChainWood in Spain in the logistic industry aims to improve traceability and examine the forestry processions efficiently [46]. This project, however, has not brought environmental improvement in wood production. One probable reason is that BT has scalability issues, meaning that it cannot store vast amounts of data, which is exacerbated by the complexity of the environment's vast numbers of data transactions [36].

4.3. Blockchain Quantification

Blockchain quantification is a systematic approach to blockchain adoption. Blockchain quantification is essential to conciliate the impact of blockchain adoption in the AFSC and to access the utility of the conciliations [3]. Most studies quantifying the blockchain focus on China and Italy [31,47]. The European Union supports launching EU-wide rules to adopt the blockchain to prevent legal and regulatory issues [48]. Blockchain quantification can be summarized into two major categories, namely primary- and secondary-based data.

The first categorization of blockchain quantification across different countries and geography relies on secondary data [16]. Several studies have used simulations to quantify the blockchain [28]. Moreover, in secondary analyses, other methods were used to quantify the blockchain by using secondary blockchain databases [6,16,26,29], or the use of data from the literature [2,6,36]. The second categorization of blockchain quantification for the AFSC or a particular product relies more on primary data [37], blockchain collection and observation [9,30], or surveys and interviews [27,31,38,49]. The primary studies were more concerned with the ex ante and ex post of blockchain implementation. Scholars suggest that among all the methods used to implement blockchain technology in the AFSC, the col-

laboration of blockchain technology and the IoT can result in a sustainable implementation in AFSC operations [30,36,50]. Among all food categories, the dairy industries in the UK and Turkey [9,49], the wine industry in Europe [28], the fish industry in Thailand [24], the bacon meat industry in China [17], and the prawn industry in Australia [25] have started implementing blockchain technology.

4.4. Trade-Offs with BT Adoption in AFSC

A few articles have highlighted the significant trade-offs of BT adoption in the AFSC. These trade-offs were introduced to minimize and balance the challenges after adopting BT in the AFSC. Based on the literature, there were a few trade-offs found, such as the cost of BT adoption [8,17], intensified competition among suppliers [17], expanded market potential [17], tampered-with information [8], and product infection [8,17].

The cost of adopting BT in the agri-food supply chain is a significant trade-off that must be carefully considered. Implementing a blockchain-based system can be expensive, requiring considerable investment in hardware, software, and personnel [8]. Infrastructure costs can also increase, as BT requires significant computing power to operate effectively. Training personnel to use the technology and comply with regulatory requirements can also increase the overall cost of BT adoption. Additionally, ongoing maintenance costs can be high, mainly if the system is complex or requires significant customization. Despite these costs, stakeholders should consider the potential benefits of increased transparency, traceability, and accountability before deciding on BT adoption [17]. Careful consideration of the specific costs involved and their impact on the bottom line is necessary to make an informed decision.

The adoption of BT can also expand the market potential for suppliers. Suppliers can appeal to a broader range of customers with greater transparency, traceability, and accountability, increasingly demanding ethical and sustainable products [25]. However, expanding the market potential may also increase competition as more suppliers enter. This competition may drive prices and reduce profit margins, lowering supplier revenues [17]. Adopting BT in the agri-food supply chain can help prevent tampering with information and product infection, but it also involves significant trade-offs. While BT provides increased transparency and traceability, it is not entirely immune to tampering or hacking [8]. Hackers may manipulate data stored on the blockchain, reducing trust in the technology and damaging its credibility.

Furthermore, inaccurate information entered into the system could lead to the wrong products being identified as the source of an outbreak, resulting in unnecessary recalls and reputational damage [8]. Implementing a BT-based system can also be expensive, with infrastructure and ongoing maintenance costs adding up, which may outweigh the benefits of improved traceability and accountability. Finally, storing a large amount of data raises privacy concerns, despite the technology being designed to protect users' privacy [17]. Balancing the benefits of increased transparency and traceability with the potential costs of tampered-with information and product infection is essential for successfully adopting BT in the agri-food supply chain.

4.5. Use of Digital Technologies

Lately, digital tools such as smart contracts, IoT devices, and HACCP have become viable solutions for the impact of blockchain adoption in the AFSC [7,32] However, a limited amount of prior literature has contributed to understanding how these technologies can ease the performance of the AFSC by collaborating with the blockchain [7,31,32]. Stranieri et al. [31] argue that these technologies can improve efficiency, responsiveness, flexibility, transparency, and food quality in the AFSC. The traditional linear food movements between AFSC stakeholders can dissolve using digital platforms to facilitate food networks [51]. For instance, Tian (2017) proposed a food traceability system combining blockchain technology and the IoT to deliver the actual time condition of the food to SC members. Blockchain technology, smart contracts, and the IoT can be connected **to** be used

in AFSC operations and enhance trust among the members of the AFSC [30]. The process of goods being transferred from producers to consumers should involve collaboration with BT and HACCP to track the food quality, temperature, humidity, and information, which was applied by Deloitte 2017 [52] for their dairy sector [32]. Furthermore, the study of Adamashvili, et al. [28] noted that BT greatly simplifies information sharing among supply chain actors. It digitizes processes, allowing for efficient tracking and tracing of products at a much lower cost and in a significantly shorter time. This can lead to improved productivity and cost-effectiveness, making it an attractive option for businesses operating in the supply chain.

4.6. Solutions to Mitigate Challenges after BT Adoption

Scholars have emphasized several strategies to minimize the impact after BT adoption [11,17,25–28,30,31,36]. Scholars should cater to the technical, organizational, and regulatory aspects [3]. These studies' strategies are broadly representable as behavioral, operational, and financial.

4.6.1. Behavioral Strategies

A linkage between behavioral strategies and BT adoption behavior was observable from the review of the existing literature. Through a qualitative study on individual user behavior in BT in the AFSC, Kramer et al. [6] developed a model to understand the factors influencing behavioral intentions towards using technology and BT. Stranieri et al. [31] have proposed an integrated conceptual framework using flexibility, efficiency, transparency, responsiveness, and food quality as performance dimensions to reduce the challenges after BT adoption while improving behavioral uncertainty among AFSC members.

4.6.2. Operational Strategies

BT adoption mainly focuses on transparency and immutability, traceability, interoperability, integration, transparency, visibility, disintermediation, decentralization, consensus mechanisms, and smart contracts that can improve the operational performance of the AFSC [26]. The other essential solution focusing on reducing the impact of BT adoption is analyzing suitable BT platforms for focal firms to coordinate AFSC activities using a vertical ecosystem that leads to smooth operations in the AFSC [6]. Adamashvili et al. [28] developed agent-based models to reduce operational costs and minimize latency after adopting BT. After observing platforms and suppliers that adopted BT, a game-theoretic model was developed by Yang et al. [8] with a focus on operational decision making in the AFSC.

4.6.3. Financial Strategies

The extant literature focuses on the reduction of impact after BT adoption in the AFSC by stabilizing the adoption cost for BT as farmers are not being paid accordingly, increased retail prices by processors [30], and increases in cost in BT adoption [17,36]. Since BT adoption increases cost, Dehghani et al. [27] posited a blockchain cloud solution to reduce the adoption cost of BT. In a similar stratum, narrowly defining the reduction of impact after BT adoption concerning economic criteria is daunting based on the far-reaching consequences of reducing the cost of BT adoption, as the knowledge of BT is still scarce. Thus, mitigating the impact after BT adoption can be enhanced if small and medium enterprises (SMEs) and industry practitioners devise a rational plan to improve the financial strategy for BT adoption in the AFSC [25].

4.7. BT towards Sustainable Development Goals (SDGs)

In addition to the benefits of nonexclusive traceability, immutability, and trust, BT contributes to sustainability performance and promotes the achievement of Sustainable Development Goals (SDGs) [24]. A quarter of greenhouse gas (GHG) is from the contribution of the AFSC globally [36,53]. Food waste generation, soil erosion, and abuse of resources are significant negative impacts of the AFSC [54]. Thus, researchers have focused on the

effects on sustainability in the AFSC after BT adoption that leads to SDGs. The literature in this area represents three significant categories, as discussed below.

4.7.1. Socioenvironmental Impact

An extensive stream of research emphasizes the importance of analyzing the effects of socioenvironmental factors to provide sustainable products and information about the origin and quality of food [29,36,40]. For example, Heinrich et al. [40] reported that producing high-value botanic products can allow supply chain members to certify and guarantee against contaminated products. The adoption of BT has enabled consumers to track the origin of their food, which also contributes to the environment and social impact [4]. An emerging focus has developed, especially in the fish industry [24,36,55,56]. Kohler et al. [29] explained how blockchain-based technologies could be adopted in the AFSC and positively affect society and the environment. According to Rana et al. [36], BT can increase transparency in the agri-food sector and facilitate the delivery of high-quality foods while reducing social and environmental impacts. By utilizing the blockchain, supply chains can be made more visible, ensuring that consumers can access accurate information about the origin and quality of the food they purchase. This can have a positive impact on both industry and society as a whole.

4.7.2. BT Supported by Information and Communication Technology

Several studies have been examined by combining information and communication technology (ICT) with BT to explore the sustainability improvements achieved in the AFSC [24,29,36]. Alonso et al. [57] illustrated that combining technologies leads to sustainable information such as product quality and origin for consumers and process optimization for producers. Implementing ICT-Blockchain can increase food production sustainability [36,50,58], as BT enables the tracking of food loss or waste [36]. The Poseidon Foundation used blockchain-based mobile apps to promote sustainable forest management and degradation [46,59].

4.7.3. Research and Development

Tsolakis et al. [24] have performed research presenting an integrated technology implementation framework and four design principles by justifying that the presence of data asymmetry can promote SDGs. Mangla et al. [9] explained that critical traceability points being evaluated under BT could also contribute to SDGs, promoting food safety, well-being, and good health for everyone. Rana et al. [36] have mainly focused on the sustainability of the AFSC using BT and have argued that many current challenges must be addressed for sustainability in food production.

4.8. Other Emerging Themes

Three significant themes related to BT adoption have emerged in recent literature. These articles are on corporate social responsibility (CSR) [6,41,42], market expansion [9,17,43], and product resilience [16,24,43]. Kramer et al. [11] have developed a technology adoption model to study the impact of BT usage behavior for managers to establish a CSR strategy to bring positive outcomes on BT investments. Similarly, Sert et al. [42] have studied how CSR is linked to operational performance in the FSC. Mangla et al. [9] have provided an assumption that the number of partners collaborating in the dairy industry in Turkey is estimated to increase to around 2800 by 2025, which clearly shows potential for network expansion. Technology stakeholders in the United States' fresh produce industry also have seen a potential expectation of network expansion [43], as have those in the China industry [17]. Collart et al. [43] have also assessed production resilience in the AFSC industry with BT adoption. For instance, the strength of fishery systems in Thailand can also be improved through BT adoption [24].

5. Potential Research Gaps and Questions

After carefully assessing the extant literature, the authors identified potential research gaps. The research gaps were mapped using the themes developed from the literature review. Table 5 presents the possible research questions and research gaps for future researchers and practitioners. Regarding the BT adoption factors, there are a few gaps identified, such as the driver of BT adoption; this paper addressed what should be empirically tested in various cultural settings and using different methodologies by solving questions such as the following: What are the most critical drivers of BT adoption? What are the role and nature of internal quality standards after BT adoption? The second category, "Impact of BT Adoption in AFSC", points out the limited research on the logistics and operational effects of BT adoption and the lack of studies on BT adoption quality management. The potential research questions revolve around understanding how BT adoption affects the operational performance and logistics of the AFSC and how a quality management system can be utilized after BT adoption. The third category, "Blockchain Quantification", highlights gaps such as the absence of socioenvironmental costing in the overall cost of BT adoption and the lack of research on the impact of BT adoption in developing countries. The potential research topics include exploring a comprehensive study of the social, economic, and environmental aspects of costing in BT adoption, analyzing the differential effects of BT adoption in developed and developing countries, and addressing the challenges of implementing BT quantification.

Table 5. Theme-based research gaps and research questions.

Theme	Gaps	Potential Research Questions (RQs)
Factors of BT adoption	1. The drivers of BT adoption need to be assessed comprehensively, focusing mainly on the AFSC stage. 2. Lack of theory-driven research in BT adoption domain factors. 3. Studies on certain types of covenants for BT adoption roles are still scarce. 4. BT's adoptions towards internal quality standards for AFSC members remain unexplored.	1. What are the most critical drivers of BT adoption? 2. How do factors affect different stages of AFSC after BT adoption? 3. How is the impact of these factors quantified? 4. What is the role of internal quality standards after BT adoption? 5. What is the nature of these quality standards adopted in AFSC after BT adoption?
Impact of BT adoption in AFSC	1. Limited number of studies on logistics and operational effects after BT adoption. 2. Limited amount of research on BT adoption quality management.	1. How does BT adoption affect the operational performance of AFSC? 2. How can logistics performance be analyzed after BT adoption? 3. How can a quality management system be utilized after BT adoption?
Blockchain quantification	1. The overall cost of BT adoption does not involve socioenvironmental costing. 2. Irregular BT adoption quantification methods. 3. Lack of research on the impact of BT adoption in developing countries. 4. BT adoption has not been figured constantly in most studies. 5. More studies on BT adoption are needed at the production level as this is the first stage in AFSC.	1. Can the current research guide potential managers to perform a comprehensive study on the social, economic, and environmental aspects of costing in BT adoption? 2. How does BT adoption differently affect developed and developing countries? 3. What are the challenges of implementing BT quantification using an affiliated approach? 4. How can farmers overcome the challenges of BT adoption at the farm level? 5. How can society acknowledge BT adoption?

Table 5. *Cont.*

Theme	Gaps	Potential Research Questions (RQs)
The trade-off of BT adoption	1. Limited research has been performed on solutions to mitigate challenges after BT adoption and the trade-off.	1. What drivers should be achieved to connect the trade-off with BT management strategies?
Use of digital technologies	1. Lack of studies explaining the benefits and improvement of BT adoption after combination with digitalization. 2. Technology development combined with BT adoption has not geographically connected with the AFSC stage. 3. Future researchers must develop inexpensive digitalization tools that can be utilized through all AFSC stages. 4. Industry 5.0 has started to be studied by a few researchers to understand how this industry can benefit from BT adoption.	1. What are the benefits and improvements of digitalization in AFSC? 2. How does digitalization vary in AFSC stages and geographically? 3. Which is the most effective cost-saving tool that can be used in BT adoption? 4. What are the advantages and disadvantages of Industry 5.0 after combining with BT in AFSC?
The solution to mitigate challenges after BT adoption	1. Awareness campaigns on BT adoption have not been explored in recent literature. 2. Various studies on practical applicability are critical towards the challenges after BT adoption. 3. Lack of theories related to BT adoption. 4. Limited number of studies on policy research based on evidence for challenges after BT adoption measures.	1. How effective are awareness campaigns on the challenges of BT adoption mitigation? 2. To what extent are the solutions suggested in recent literature practically applicable to the challenges after BT adoption? 3. What contextual variables are involved based on reducing challenges in BT adoption? 4. How do these contingency theories quantify this effect? 5. How does policy intervention influence the AFSC stages?
BT towards SDGs	1. Limited number of studies on how BT adoption leads to the circular economy. 2. There is a lack of studies on how BT adoption models help mitigate the challenges after BT adoption and digital technologies. 3. Limited focus on implementation strategies to improve the performance in AFSC after BT adoption.	1. How does BT adoption lead to the circular economy? 2. How can BT adoption models help mitigate the challenges after adoption along with digital technologies? 3. Which are the potential strategies that can be implemented to improve the performance of AFSC after BT adoption?
Other emerging themes	1. Studies on CSR activities related to BT adoption are still scarce.	1. What potential CSR activities can be implemented to inspire BT adoption?

The fourth category, "The Trade-off of BT Adoption", brings attention to the limited research on solutions to mitigate challenges after BT adoption and the trade-off. The potential research question emphasizes identifying the drivers that can connect the trade-off with BT management strategies. Likewise, the fifth category, "Use of Digital Technologies", highlights the lack of studies explaining the benefits and improvements of BT adoption combined with digitalization and the need for inexpensive digitalization tools applicable across all AFSC stages. The potential research questions involve exploring the benefits and improvements of digitalization in the AFSC, understanding the geographic and stage-based variations of digitalization, and evaluating the advantages and disadvantages of Industry 5.0 combined with BT in the AFSC.

The sixth category, "The Solution to Mitigate Challenges after BT Adoption", addresses gaps such as the lack of awareness campaigns and theoretical frameworks related to BT adoption, as well as the limited number of studies on policy research for postadoption challenges. The potential research questions focus on assessing the effectiveness of awareness campaigns, evaluating the practical applicability of suggested solutions, understanding contextual variables influencing challenges in BT adoption, and examining the impact of policy interventions. The seventh category, "BT Towards SDGs", highlights the limited number of studies on how BT adoption contributes to the circular economy, the role of BT adoption models in mitigating postadoption challenges, and the need for implementation strategies to improve AFSC performance after BT adoption. The potential research questions aim to understand the relationship between BT adoption and the circular economy, explore the role of BT adoption models in overcoming challenges with digital technologies, and identify effective strategies to enhance AFSC performance. Finally, the table mentions the scarcity of studies on corporate social responsibility (CSR) activities related to BT adoption. The potential research question revolves around identifying potential CSR activities that can inspire BT adoption. However, these gaps and questions highlight areas where further research is needed to deepen our understanding of the impact, challenges, and potential solutions associated with BT adoption in the agricultural and food supply chain.

6. Implications of the Study

The present study has provided critical theoretical and practical implications. Several review studies have investigated the impact of BT adoption in the AFSC and mainly focused on events prior to adoption. The present research has advanced the extant literature and explored the critical areas after BT adoption in the AFSC.

This study has systematically gathered knowledge within highlighted areas using scholarly attention deficiency by conducting a thematic analysis. The analysis showed that the recent literature on the impact of BT adoption in the AFSC leads to the factors responsible for the effects after BT adoption in the AFSC. The thematic analysis approach used in this study will be a foundation for future researchers to explore and extend their scope by considering the development of digitalization and the circular economy for the challenges after BT adoption mitigation in the AFSC. Furthermore, analyzing themes and research profiling in the literature rejuvenate scholars' understanding concerning the issues associated with BT adoption. Focusing on and highlighting the themes, such as solutions to mitigate the challenges after BT adoption in the AFSC, BT quantification, and factors responsible for the impact after BT adoption in the AFSC, led to the study pathway and contributes to the global agenda for solutions to mitigate BT adoption in the AFSC. Using a research profiling approach, the SLR points were gathered based on geographic location, AFSC stages, and product groups.

This study identifies the potential research questions and research gaps to mitigate these gaps by pointing out some critical research questions. Thus, this work has contributed to future research agendas. The recent SLR divulges future studies that should be considered while evaluating the impact of BT adoption in the AFSC. The effect should be analyzed in terms of the socioenvironmental factors as well. The present study highlights the need to shift attention towards focusing on the impact after BT adoption. Finally, this study provides a systematic summary of the impact after BT adoption and constructs an action plan to offer solutions to mitigate the effects after BT adoption.

The present study has provided six dominant implications for practitioners associated with the AFSC. Producers should understand the problems developed after BT adoption in the AFSC as their tasks and responsibilities play a vital role in BT adoption in the AFSC. The critical points for practitioners are summarized below.

The thematic foci presented in this study can help producers and all the members of the AFSC to have a worm's eye view of the scope and depth of the issues associated with BT adoption in the AFSC. For instance, there is evidence from the literature that the adoption of the blockchain causes incentive conflict between local suppliers and overseas suppliers

due to a higher procurement price that affects the market share and profit margin due to the high cost of blockchain adoption [17]. Next, the method of quantifying BT adoption needs attention. The literature states that BT quantification logs their data using several methods. Proper guidelines need to be developed to assist the AFSC members with accurate BT quantification focusing on the magnitude of the problem. Additionally, the exaggeration of the monetary value of BT adoption needs to be exchanged with a BT quantification strategy that includes socioenvironmental impacts.

AFSC members need to understand the importance of digital technologies for managing and mitigating BT adoption. Digitalization principles can help minimize the impact of BT adoption in the AFSC [31]. Furthermore, producers such as farmers who acknowledge the importance of BT adoption in the AFSC must learn and support the development of infrastructure on new technologies such as the IoT, which helps smoothen the data tracking process in the AFSC. This is necessary for businesses as, in the future, most of the food business will be driven by data, which might exclude those not used to this technological development. Despite that, most empirical studies focus on BT adoption drivers regarding AFSC stages, product categories, and geographic location. To hypothesize the findings, all AFSC members should uphold their studies with their input. Verification from the AFSC members will highlight any potential deficiencies, if there are any, with the theoretical findings that the recent literature offers.

The subsequent implication that AFSC members should understand is the impact of BT adoption in the AFSC. The studies on BT adoption with sustainability highlight the effect after BT adoption in the AFSC that can be achieved by focusing on SDGs [24,36]. Achieving sustainability using BT adoption in the AFSC can guide the AFSC members to manage resources efficiently. By adopting the solution to mitigate the impact after BT adoption in the AFSC, this study can guide AFSC members towards understanding the importance of allocating resources efficiently. The final implication can provide policymakers with ideas and guidelines to devise policy mediation for BT adoption issues. Policymakers also play a dominant role in several cases. As is evident from the literature, policymakers rely more on product traceability and the transparency of agricultural processes in developing policies related to BT and the AFSC. However, most of the blockchain implementation in the AFSC prioritizes these two terms [2]. Policymakers should also focus on components such as product resilience and sustainability with BT adoption. The findings have provided a pathway for them to perform a reality check starting from ground-level conditions rather than focusing more on product traceability and transparency.

7. Conclusions, Limitations, and Suggestions for Future Studies

The present SLR involved critical research on the impact of BT adoption in the AFSC. This study makes diverse contributions to the contemporary literature. As for the first contribution, the theory, the SLR used the existing research and carefully organized the key contributors, countries of origin, publication timelines, and 27 articles. The analysis disseminates that the research in this area has remained chiefly scattered. The literature on the impact after BT adoption in the AFSC overlaps the domain of researchers, the level of analysis, and various methodologies, and expands across multiple journals. The earlier reviewed studies focused more on the ex ante of BT adoption and presented BT adoption in the AFSC, and the main focus was on the AFSC stages. However, the present study demonstrated a detailed literature analysis and gathered dominant themes in their entirety. Thus, the second contribution is dividing the literature based on the key terms that led to recognizing the crucial topics for BT adoption research. The following are the key themes: (a) the factors of BT adoption; (b) the impact after BT adoption in the AFSC; (c) blockchain quantification; (d) the trade-offs of BT adoption; (e) the use of digital technologies; (f) solutions to mitigate challenges after BT adoption in the AFSC; (g) BT moving towards SDGs; and (h) other emerging themes. Based on the literature analysis, the factors responsible for BT adoption in the AFSC are food traceability and transparency, food safety and security, food supply and logistics, food integrity, and food waste and environmental

awareness. The present SLR also has presented the solution to mitigate challenges after BT adoption in the AFSC from the literature. The final contribution of the SLR is that the review was concluded by delineating the gaps and potential research questions to guide future researchers and framework development.

This review has elucidated the state of BT adoption in AFSC research. However, there are limitations that future researchers can take up to review or study. First, the authors only focused on English journals on the Web of Science (WOS) database. Therefore, some appurtenant studies were possibly missing from the present SLR. Future SLRs can also explore journals in other languages, proceedings papers, and book chapters by using different databases. Furthermore, we have focused on article selection using the inclusion and exclusion approach and excluded conceptual studies. This scope and study would have completed the recent review but were excluded due to scope constraints. Last but not least, the scope for the digitalization of technologies and sustainability combined with BT adoption is embryonic. Nevertheless, future researchers would have used these studies as guidance for future studies. However, with the expansion of the digitalization era, some of the findings may be useful in the future. Even so, this research has provided information on the emerging themes of BT adoption for future literature. Henceforward, it would be constructive to carry out a bibliometric study to provide a deeper understanding of the impact after BT adoption in the AFSC by comparing the development of BT adoption in other countries. The authors hope the present study can be helpful for future researchers and practitioners to explore more in this area.

Author Contributions: Conceptualization, M.H.A. and L.H.O.; methodology, L.Y.; formal analysis, L.Y. and M.M.; data curation, L.Y. and S.S.A.; writing—original draft preparation, L.Y., M.M. and S.S.A.; writing—review and editing, M.H.A., N.K. and L.H.O.; supervision, M.H.A. and L.H.O.; project administration, M.H.A.; funding acquisition, M.H.A., L.H.O. and N.K. All authors have read and agreed to the published version of the manuscript.

Funding: The authors acknowledge the Fundamental Research Grants Scheme (FRGS), grant number FRGS/1/2021/SS01/UKM/02/1 funded by Ministry of Higher Education (MOHE), Malaysia, and the part of this research is supported by EP-2020-028 funded by MPOB-UKM.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest.

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The Impact of Government Food Policy on Farm Efficiency of Beneficiary Small-Scale Farmers in Indonesia

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Abstract: Enhancing self-sufficiency and national food security have been strategic policy goals of the Indonesian government. From 2015 to 2019, a food policy program called *Upsus Pajale* had been implemented to provide input subsidies and extension assistants to farmers for three strategic commodities: rice, maize, and soybeans, to accelerate productivity and increase production. The study was done by interviewing 374 beneficiary farmers. The objectives were to explore production efficiency and the farmers' perspectives on the policy programs. By conducting stochastic frontier production function estimation, the results show that the mean efficiency level was 0.866. This study revealed that land size, seed cost, and labor cost were found to be important determinants of technical efficiency. In addition, the results of the inefficiency model indicated that age and farmers' associations had a significant and positive effect on efficiency scores, whereas education had a negative effect. Contrarily, none of the policy program instruments appear to be essential determinants of efficiency. Furthermore, the research found that farmers prioritized their habits and profitability when deciding which crop to cultivate and that pests were their main concerns. Hence, the government should focus on enhancing research and development for improved seedling pest management control and encourage the establishment of farmers' association to share experience and transfer information and technology for farmers to improve their efficiency.

Keywords: food policy; technical efficiency; stochastic frontier; strategic commodities

Citation: Purnamasari, M.; Huang, W.-C.; Priyanto, B. The Impact of Government Food Policy on Farm Efficiency of Beneficiary Small-Scale Farmers in Indonesia. *Agriculture* **2023**, *13*, 1257. https://doi.org/10.3390/agriculture13061257

Academic Editors: Hung-Hao Chang, Pei-An Liao and Jiun-Hao Wang

Received: 25 April 2023
Revised: 10 June 2023
Accepted: 13 June 2023
Published: 16 June 2023

1. Introduction

Zero hunger reduction is one of the focuses of the Sustainable Development Goals (SDGs), and specially SGD 2. Over the last decade, the world has been committed to reducing hunger and poverty. The number of undernourished people in developing countries has fallen by almost half, from 23.3% in 1990–1992 to 12.9% in 2014–2016 [1]. The international community stepped up their commitment to combat hunger by adopting the 2030 Agenda for Sustainable Development, especially SGD 2. The target is to end hunger, ensure food access, end all forms of malnutrition, and double the agricultural productivity and income of small-scale food producers [2]. In achieving the 2030 Agenda for SGD 2, supporting agricultural development is essential to ensure sustainable food production systems and double the agricultural productivity and incomes of small-scale food producers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets, and opportunities for value addition and non-farm employment. Although developing countries tend to show greater reliance on farming activities, food production and consumption are fundamental to any

economy and pervade every society [3]. Consequently, there is no doubt that every country is always trying to ensure national food security.

In order to achieve food security and ensure sustainable food production, many nations are focusing on a strategy of food self-sufficiency by providing various agricultural policy programs. The policies are aimed to increase production, improve productivity, and enhance the production areas. In Thailand, the Thai government has attempted to enhance rice production by expanding the area and increasing their productivity by encouraged the farmers to use new technology such as high-yielding cultivars and improve agricultural tools [4]. Furthermore, this intervention will also simultaneously raise wages, reduce food prices, and promote economic growth [5]. The concept of food self-sufficiency is taken as the ability of the country to satisfy its food needs through its domestic production. The merits of food self-sufficiency as a national policy goal will provide both economic and political benefits. As an economic development strategy, it might strengthen the country's domestic farm sector, reduce production shortfalls in other countries, or cause sudden and sharp rises in food prices. Moreover, the study conduct by Puma MJ et al. [6] showed that developing countries suffer greater import losses through their increased dependence on imports for staple foods. Politically, it is not only a strategy for building national pride, but also a means by which to reduce vulnerability on the world political stage stemming from over-reliance on other countries for essential supplies [7].

Several nations have elevated food self-sufficiency on their policy agendas in response to the extreme food price volatility experienced during the 2007–2008 food price crisis and its aftershocks. Globally, a previous study found that around 77% of the world's countries are in calorie deficit [8] and 83% of countries have low or marginal food self-sufficiency [6]. Regardless of whether they are developed or developing countries, various nations, including Senegal, India, the Philippines, Qatar, Bolivia, and Russia, have indicated a desire to increase their food self-sufficiency, because countries that are not food self-sufficiency may have no problem in securing adequate food supplies for their population through a reliance on international trade [8,9]. High-income or developed countries can afford to import food regardless of whether food prices are high or volatile on international markets, while other countries may find it extremely difficult to import enough food for their population. In addition, hunger and poverty issues arise when a developing country continues to rely on imports, particularly for its staple foods.

Indonesia is one of the developing countries where food self-sufficiency has risen to the top of the political agenda for its government. It has been decades since the staple food consumed, rice, in Indonesia has relied on imports to fulfill domestic needs. For more than 32 years, Indonesia has been unable to meet its population's needs through domestic production of rice and other strategic commodities that serve as reliable foods for the population, such as maize and soybeans. Despite being the world's third-largest rice producer, Indonesia is also one of the world's largest rice consumers. As the population has risen 5.74 percent in 2010 to 2014, rice imports have increased by 18.57 percent, from 687,582 tons in 2010 to 815,285 tons in 2014 [10]. Maize imports rose by 107.9% from 1,527,516 tons in 2010 to 3,175,362 tons in 2014, owing to a rise in demand per capita of 1.97 kg per year in 2015, and it increased by approximately 9.92 percent from 2011 to 2015. Soybeans are consumed as a raw or industrialized product by Indonesians. In 2014, per capita consumption was 7.13 kg. The imports of soybeans rose by 12.85%, from 1,740,505 tons in 2010 to 1,964,081 tons in 2014 [10].

As a response, in 2015 to 2019, the Indonesian government implemented a food self-sufficiency policy in order to achieve national food security for strategic commodities such as rice, maize, and soybeans in four years after the policy was implemented. The food policy program is called *Upsus Pajale*. Both strategies and efforts are made in the *Upsus Pajale* programs to increase production through increasing area and productivity. The program is officially administered by the Ministry of Agriculture under the formal regulation number 14/PEMENTAN/OT.140/3/2015. Farmers of rice, maize, and soybeans gradually received one-time government subsidies, such as seeds, fertilizer, chemicals, machinery (tractors),

and reconstruction of damaged infrastructure (irrigation canal systems). The extension officer and researchers from the Agricultural Service Center also provide intensive farm technical assistance to help farmers increase the productivity of their farms. Moreover, the Ministry of Agriculture cooperates with universities (students and lectures) and the Indonesian Army (*Babinsa*) to facilitate training and solve the farmers' problems as part of *Upsus Pajale* programs. The program was held gradually starting from the central of production areas of the following provinces: East Java, Central Java, North Sumatra, South Sulawesi, Jambi, West Kalimantan, South Kalimantan, and Central Kalimantan as the priority areas of the program (Figures 1 and 2) [10]. The Indonesian government believes that these programs will play an important role in increasing production, improving productivity, increasing farmers' income, and ultimately contributing to increased national food security.

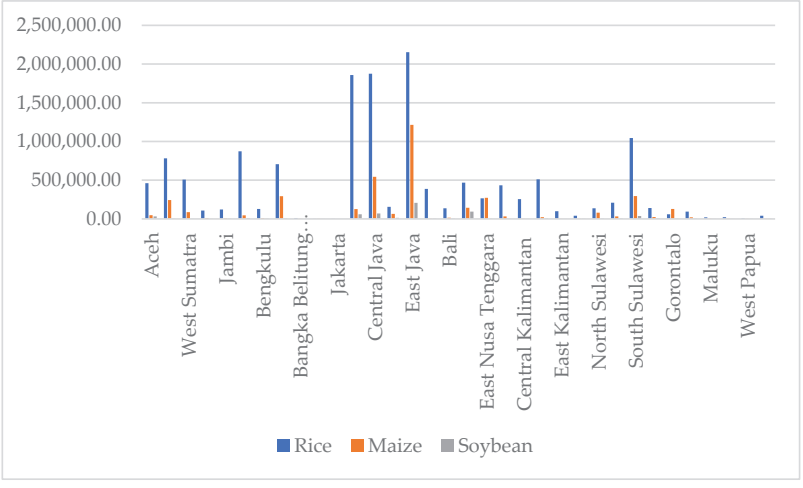

Figure 1. The area of rice, maize and soybean in Indonesia in 2014. Data source: Central Bureau of Statistics Republic of Indonesia.

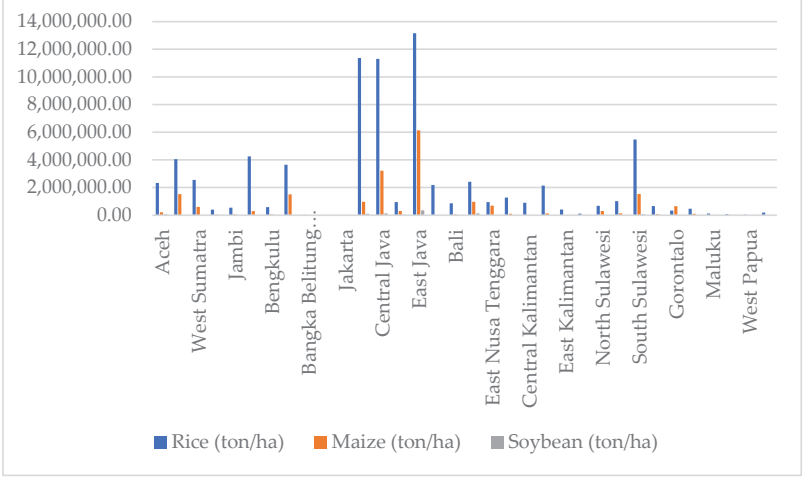

Figure 2. The production of rice, maize and soybean in Indonesia in 2014. Data source: Central Bureau of Statistics Republic of Indonesia.

Recently, Indonesia has continued to import these three commodities. According to the Central Bureau of Statistics of the Republic of Indonesia, rice imports in 2014 reached 844,163.7 tons and decreased to 429,207.3 tons in 2022. Meanwhile, maize imports decreased from 3,300,000 tons in 2014 to 995,990 tons in 2021. In the meantime, imports of soybeans decreased from 2,671,914.1 tons in 2017 to 2,324,730.8 tons in 2022. This situation demonstrates that the *Upsus Pajale* programs are not performing as well as the Indonesian government had expected. This fact is also in line with research conducted by Juhandi [11], which revealed that the goals of the Upsus Pajale policy have not been achieved and the production of priority provinces of the program has not changed much before and after the *Upsus Pajale* program was implemented [11]. Therefore, it is interesting to look again at what and how the impact of this policy has affected farmers who were beneficiaries of the subsidies programs at the micro level, as well as explore what problems farmers faced that might have prevented the target of self-sufficiency in rice, maize, and soybeans from being achieved.

Various studies have found that policy programs by providing financial and economic incentives such as subsidies have a positive impact on productivity [12,13]. The *Upsus Pajale* is expected to increase production by increasing farm productivity, which is in line with the assumption of increasing farm efficiency in order to maximize profit with low production costs. Therefore, after applying the policy program, the question arises, "what is the farm performance of the farmers involved in the programs?" Efficiency could be evaluated to determine whether a farm is producing the highest level of output potential given the resources being used [14]. Furthermore, to increase the productivity, it is important that farmers are able to utilize their farm resources efficiently by improving their technical efficiency [15]. Frontier efficiency is an essential analysis and has received substantial attention as one of the indicators to assess the technical efficiency of agricultural production performance [12,16–24].

Analyzing the technical efficiency using stochastic frontier analysis (SFA) is somehow still a popular and reliable calculation of the efficiency level and factors that influence inefficiency. To the authors' knowledge, in Indonesia, there are only a few empirically based studies evaluated the impact of the *Upsus Pajale* program [11,25–29]. Most of those studies analyzed the factors that influence the inefficiency using characteristic demographics and social economics of farmers' household [18,30–32]. This study focused on the subsidy's instruments of program as variable indicators affecting inefficiency level which has not been analyzed. Furthermore, to provide more comprehensive research the study explored the farmer's perception and agricultural problems they faced in managing their farm. Therefore, the study aims to analyze the technical efficiency of the farmers by employing SFA, and by using the same questionnaire, the close-ended survey questions were utilized to discover the farmers' perspectives on the *Upsus Pajale* program as well as to find out the problems that farmers faced in farming. As such, the present study would fill up the gap in the literature. In the hope that this study could provide a more comprehensive assessment of the program's impact on farmer beneficiaries of *Upsus Pajale* policy programs.

The subsequent sections of the article are organized as follows: materials and methods, empirical results and discussion, conclusion and policy recommendation, and limitations and future recommendations.

2. Materials and Methods

2.1. Study Area and Sampling Design

Data were collected by close-ended survey questionnaires in Jember, East Java province, Indonesia (Figure 3). East Java is the largest production area of rice, maize and soybeans in Indonesia (Figures 1 and 2), and it was also the one of priority province for *Upsus Pajale* policy programs. Jember accounts for the highest rice production area compared to other regions in East Java and produced 998,559 tons of rice in 2015. In the same year, for maize and soybeans, Jember ranked second and fifth, respectively, among 38 regions in East Java; it produced 427,064 tons of maize and 25,178 tons of soybeans. The sample of our

study was the farmers who have been receiving one of the subsidies from the *Upsus Pajale* policy programs. Due to the data limitations, the population number of farmers that were beneficiaries of the subsidies from the *Upsus Pajale* program was unknown, therefore the authors collaborated with the extension officer from Technical Implementations Unit of the Agriculture Department (UPTD) from the Ministry of Agriculture to run interviews. The reason for this is, because they are the ones who execute the program, they therefore know accurately which farmers were the beneficiaries of the *Upsus Pajale* program. The interviewers received instructions and conducted a survey from October to December 2016.

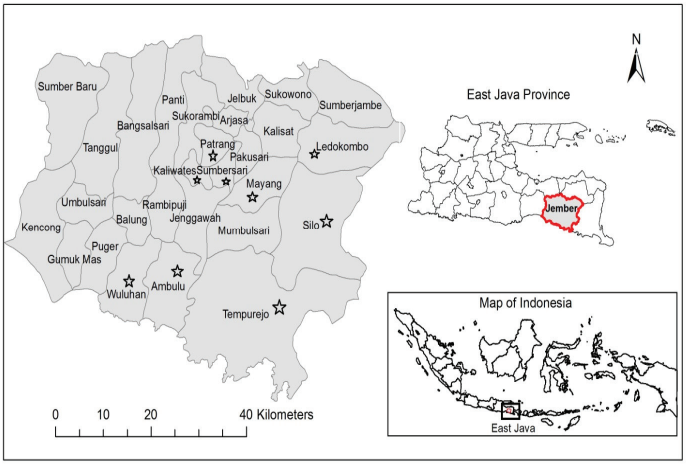

Figure 3. Map of Jember, East Java province, Indonesia. Note: In the figure, the stars sign represent the study areas.

This research used the multi-stage procedure for sampling design. This sampling method was ideal to be used when it was impossible or impractical to compile a list of the elements composing the population [33]. Jember has 31 districts and 10 UPTD, with each UPTD covering 3 to 4 district areas. The following UPTDs were chosen: UPTD Silo, UPTD Sumbersari, and UPTD Ambulu. These three UPTD have the most farm households, the largest production areas, and the highest productivity. These areas also have similar agro-ecologies (rain-fed and irrigation systems). In total, there were 9 districts targeted: Silo, Mayang, Ledokombo, Sumbersari, Kaliwates, Patrang, Ambulu, Wuluhan, and Tempurejo. In total, there are 70 villages in those 9 districts, and we randomly selected 42 villages as representatives. A total of 450 questionnaires were distributed. After removing invalid samples, which include incomplete questionnaires, the dataset consisting of 374 qualified farmers was used for analyses. By using the data, the study was able to explore the assessment of farm efficiency and discover farmers' perceptions of the *Upsus Pajale* program. In addition, this study also tried to explore the agricultural problems that farmers faced. The survey collected detailed information on three aspects. First, socio-economic characteristics of the farmers' household, i.e., gender, age, education, farming experience, and household size. Second, farm resource data, i.e., farm output production, farm size, and inputs, were used. The third was the farmers' general impression of the program and the agricultural problems they faced.

2.2. Theoritical Model

There are three concepts of efficiency: technical efficiency, price/allocative efficiency, and economic efficiency [34]. Farmers have higher technical efficiency compared to others if they could produce more output by using the same number of inputs. Price efficiency, or allocative efficiency, measures farmers' efforts to maximize profit, which is achieved

when the marginal product value of each factor of production equals the marginal cost. Economic efficiency is a combination of technical efficiency and price efficiency.

The stochastic frontier analysis (SFA) model was introduced by Aigner et al. [35] and Meeusen W, van den Broeck [36] and has been an important parametric approach to estimating the production frontier and factors influencing efficiency. The main strength of SFA models, also known as composed error models, is that they postulate the existence of technical efficiency in farm production that is involved in producing a particular output [16,17]. Theoretically, the inefficiency model is not explicitly formulated in terms of appropriate explanatory variables. The general model of stochastic frontier production function that assumes the technical inefficiency of production can be represented as:

$$y_i = f(x_{i,}\beta) + \varepsilon_i \text{ for } i = 1, 2, \ldots n \tag{1}$$

where y_i is the output of the *i*-th farm; x_i is the vector of input; β is vector of unknown parameters to be estimated; and ε_i is error term. The error term (ε) consists of two independent components,

$$\varepsilon_i = v_i - u_i \tag{2}$$

where v_i is a two-sided error term that represents statistical noises, which is assumed to be independently and identically distributed $(i.i.d)N(0, \sigma_v^2)$ and it captures the effect of random shocks outside the farmers' control (such as bad weather, luck, natural disaster, unpredictable variation in equipment performance, etc.); u_i is a one-sided error term that represents technical inefficiency, assumed to be independent to x_i and v_i, and it capture the effect of factors under farmers' control. The error component of $u_i = |u_i|$, where u_i is $(i.i.d)N(0, \sigma_u^2)$. It implies that u_i is half-normal but it also can be replaced by other assumptions, such as truncated-normal [37] and two-parameter gamma [38].

Referring to Battese and Coelli [17], we assumed that u_i is truncations (at zero) of the normal distribution with mean, $z_i\delta$, and variance, σ_u^2. The production technical inefficiency effects can be described as:

$$u_i = z_i\delta + w_i \tag{3}$$

where δ is a $1 \times p$ vector of parameters to be estimated and z_i is a $p \times 1$ vector of variables that may influence the efficiency of the *i*-th farm-specific variable hypothesized to be associate with technical inefficiency. The distribution range of the random errors v_i is $[-\infty, +\infty]$, while the distribution range of the random inefficiency factor u_i is $[0, +\infty]$, and w_i is a truncated random error $(\geq -z_i\delta)$. Given the input vector, x_i, the potential output is defined by the frontier function, $y^* = exp(x_{i,}\beta + v_i)$. The mathematical expectation (mean) of technical efficiency of *i*-th farm can be obtained as the ratio of the observed output for the *i*-th farm, relative to the potential output, which can be explained as follows:

$$TE_i = y/y^* = E[exp(-u_i|\varepsilon_i)] \qquad i = 1, 2, \ldots, n \tag{4}$$

where TE_i is technical efficiency *i*-th farmer, $E[exp(-u_i|\varepsilon_i)]$ is expected results (mean) from u_i, $0 \leq TE_i \leq 1$. If the $TE_i = 1$, the farming in efficient level condition.

In this research, the Cobb–Douglas frontier will be used. Transforming to the logarithm form yields:

$$\ln y_i = \ln \beta_0 + \sum_{j=1}^{n} \beta_{\mathrm{ij}} \ln x_{\mathrm{ij}} + v_i - u_i \tag{5}$$

where y is output; x_{j} is the j-th input; i is *i*-th farmer, $\beta_0, \beta_{\mathrm{ij}}$ are parameters; $v_i - u_i$ is error term. The detail empirical model specification for the Cobb-Douglass production function of rice, maize, and soybean in Indonesia is:

$$\ln(y_i) = \ln \beta_0 + \beta_1 \ln(x_1) + \beta_2 \ln(x_2) + \beta_3 \ln(x_3) + \beta_4 \ln(x_4) + v_i - u_i \tag{6}$$

where y_i represents the quantity of output (in kg/farm); x_1 is the land size (in hectar); x_2 is the cost of seeds used in the farming areas (in rupiah/farm); x_3 is the cost of fertilizer

used in the farming areas (in rupiah/farm); x_4 is the total cost of labor used in the farming process (in rupiah/farm); β is an unknown parameter to be estimated along with the variance parameters and if the expected estimated coefficient: $\beta_1, \beta_2, \beta_3, \beta_4 > 0$, the positive sign of each variable will increase the production of the crop. The inefficiency effect model captures the social–economic variables and subsidies instrument that the farmers received from the *Upsus Pajale* programs. These variables might be possible to influence technical efficiency, as defined by:

$$u_{\mathrm{i}} = \delta_0 + \sum_{j=1}^{11} \delta_j z_{ji} \tag{7}$$

where the δ_0 is intercept; δ_j is unknown parameter of 11 variables; z_1 is farmer's gender (man = 1; woman = 0); z_2 is farmer's age (years old); z_3 is farmers education level; z_4 is family numbers (person); z_5 is farming experienced (year); z_6 is a dummy for joint farmer's association (1 if join; 0 otherwise); z_7 is a dummy variable for received seed subsidies from government (1 if received; 0 otherwise); z_8 is a dummy variable for received pesticide subsidies from government (1 if received; 0 otherwise); z_9 is a dummy variable for received fertilizer subsidies from government (1 if received; 0 otherwise); z_{10} is a dummy variable for received machinery subsidies from government (1 if received; 0 otherwise); and z_{11} is agricultural extentions (the number of training/assistants that farmers have received in a year). The subsidies instruments in the study used dummy variable because the subsidies type and numbers that farmers received varied. The maximum likelihood estimates of the parameters were estimated using the computer program FRONTIER, version 4.1, developed by Tim Coelli in 1996.

This study also investigated the farmers' perspective about the *Upsus Pajale* program to discover general perception of the policy. Close-ended questions with multiple choice and Likert scale were used. The Likert scales are one of the most commonly used scales in social science research, and this measurement can measure the attitude of the respondents quickly and easy to make statements to capture the essence of a specific construct. It is also easy to understand, and respondents feel it easy to provide their perception through a Likert-type format [39].

3. Results and Discussion

The descriptive statistics of the social economic variable are presented in Table 1. The average farmers age of this study was 46.9 years old; 3.310 levels of education which could be qualified as junior high school; with 3.4 members of family; and the average number of farming experience around 21.69 years. The variables used in this study with their respective descriptive statistics are presented in Table 2. The farms involved were found to be relatively small-scale farmers with an average of less than one hectare. Labor costs stood as the highest compared to seed and fertilizer with an average of 2,582,374.564 rupiahs (190.7 USD). The average seed cost used for the planting season was 399,205.214 rupiah (29.5 USD), while the fertilizer cost was higher at 1,138,455.249 rupiah (84.07 USD). The average output was recorded at 4596.6 kg/farm.

Table 1. Descriptive statistics of the social economic variable of the sample.

Variables	Unit	Max	Min	Mean	Std. Deviation
Age	years	80	5	46.960	10.244
Education	level	10	0	3.310	1.8555
Family size	number	8	1	3.404	1.118
Farming experience	years	60	1	21.690	10.569

Table 2. Descriptive statistics for variables used in the study.

Variables	Unit	Max	Min	Mean	Std. Deviation
Output	kg/farm	22,000	300	4596.553	3411.384
Land size	hectare/farm	4	0.1	0.711	0.502
Seed cost	1IDR/farm	2,400,000	15,000	399,205.214	389,798.598
Fertilizer cost	1IDR/farm	5,650,000	36,000	1,138,455.239	674,806.721
Labor cost	1IDR/farm	10,600,000	100,000	2,582,374.564	1,856,451.483
Subsidy seed	dummy	1	0	0.888	0.316
Subsidy Pesticide	dummy	1	0	0.102	0.303
Subsidy Fertilizer	dummy	1	0	0.297	0.457
Subsidy Machine	dummy	1	0	0.088	0.284
Agricultural extension	number/year	24	0	5.307	5.425

IDR: Indonesian currency (Rupiah); 1USD = 13,540.89 IDR as of December 2016.

The model of efficiency in Table 3 explains the stochastic frontier production function (SFPF) estimation result for farmers that received subsidies from the *Upsus Pajale* program in Indonesia using the Cobb–Douglas production model. Both the ordinary least squares and maximum likelihood analyses show that land size, seed cost, and labor cost were positive and significant at the 1% significance level, while fertilizer cost remained not significant at the 5% level. This means the output will increase as land size, seed, and labor increase. These results imply that when land (total area planted for the crops), seed cost, and labor cost are increased by 1%, it will lead to an increase in the quantity of crops harvested by 0.65, 0.18, and 0.14, respectively. Land became the most crucial factor for production. The results are in accordance with several studies that indicated that land had a strong impact on production, for example [4,40–42]. In addition, the typical Indonesian farmer is a small-scale farmer with a small farmland area, which makes the use of large machines difficult. Therefore, labor-intensive methods were most widely used instead machines, and the same results were estimated by [4,15,23,42,43]. Furthermore, the seed cost also has a positive influence on efficiency. This finding is consistent with the statement of Vu, Thi-Hien et al. [23], found that increasing the seed could boost the yield. Moreover, Haryanto et al. [44], and Chiona et al. [45], the used of certified seed which tends to be more expensive but observed to have higher technical efficiency. In short, the results suggested that farmers should adjust and allocate input factors such as land, seed, and labor appropriately to improve efficiency and in turn, this could further contribute to increase productivity and boost the national production.

Meanwhile, the maximum likelihood estimation result showed that the variance parameter (γ) was found to be highly significant at 1% level and the coefficient was found to be 0.89, indicating that there was a technical inefficiency that influenced the farming production in the study area. The higher share (0.89) of the efficiency of rice, maize, and soybeans was caused by farmers' farming management, while the other (0.11) was due to random errors that are out of the farmers' control. Based on the sigma squared (δ^2) results, we might know the diffrence of the reality that happened in their farming management system and the potential farming system. The result showed that sigma squared was bigger than zero, which was 1.03 and significant at 1% level, indicating that there was technical inefficiency.

The technical inefficiency effects in the lower half of Table 3 showed that the positive coefficient indicated that the variable has a positive influence on technological inefficiency, while the negative sign is the opposite. The more the estimated value differs from zero, the stronger this efficiency or inefficiency is. From the 11 factors of farmers' socioeconomic variables and policy instruments, inefficiency appears to be significant for the following variables: farmers' age and farmers' education at a 5% significance level, while the factor of joint farmers' association is statistically significant at a 1% significance level.

Table 3. The parameter technical efficiency.

Variables	Parameter	OLS			MLE		
		Coefficient	Standard-Error	*t*-Value	Coefficient	Standard-Error	*t*-Value
Efficiency Model							
Constant	β_0	3.83	0.87	4.38	3.96	0.77	5.13
Ln Land size (ha)	x_1	0.65	0.06	11.46 **	0.63	0.05	11.62 **
Ln Seed cost (IDR/farm)	x_2	0.18	0.03	5.70 **	0.22	0.03	8.18 **
Ln Fertilizer cost (IDR/farm)	x_3	0.02	0.04	0.49	0.00	0.04	0.00
Ln Labor cost (IDR/farm)	x_4	0.14	0.04	3.40 **	0.14	0.04	3.50 **
Inefficiency Effects							
Constant	δ_0				5.38	2.50	2.15 *
Farmer gender; 1 = Man; 0 = Woman	z_1				−1.89	1.70	−1.11
Farmer age (year)	z_2				−0.06	0.02	−2.38 *
Farmer education level	z_3				0.32	0.13	2.51 *
Family number (person)	z_4				−0.25	0.14	−1.84
Farming experienced (year)	z_5				0.00	0.02	−0.15
1 if joint farmer association; 0 otherwise	z_6				−4.21	1.38	−3.04 **
1 if received seed subsidy; 0 otherwise	z_7				−1.05	0.56	−1.89
1 if received pesticide subsidy; 0 otherwise	z_8				−0.15	0.83	−0.18
1 if received fertilizer subsidy; 0 otherwise	z_9				0.91	0.48	1.88
1 if received machinery subsidy; 0 otherwise	z_{10}				−2.54	1.45	−1.76
Agricultural extension (number/year)	z_{11}				0.07	0.04	1.73
Sigma-squared (δ^2)		0.36		0.21	1.03	0.27	3.79 **
Log likelihood function				−233.62			−202.84
Gamma (γ)		0.68			0.89	0.03	30.22 **
LR					61.55		

t-value at significance at 5% and 1% level correspond to * and **, respectively.

The coefficient of the farmers' age variable showed a negative relationship with the predicted inefficiency and was significant at the 5% level, implying that technical inefficiency will be reduced by 0.06 percent as the farmers' age increases. It seems that older farmers have more skills to apply and operate the farm than their younger peers, who may lack years of experience, which is consistent with the findings of Vu, Thi-Hien et al. [23] and Chiona et al. [45]. The coefficient of education level was significant at the 5% level; however, it had an unexpected sign; it was a positive sign. It implies that the higher the education of the farmers, the more inefficient their farms are; this result is in contrast to [15,23]. The reason was that in the study area, highly educated farmers tend to do farming as their second job. Therefore, they do not concentrate on the farming sector mainly, but busy themselves with their primary jobs as public officers, teachers, or sellers. These results are similar to Kune, S.J., et al. [46], who found that formal education negatively influenced the Indonesian maize efficiency level. Joining the farmers' association played an important role in reducing inefficiency. The variable was significant at the 1% level, with a negative relation to the inefficiency effect. This condition indicates that farmers who join a farmer's association tend to be more efficient; these results are in agreement with Ayodeji, O., et al. [47]. Farmers most likely receive more benefits from their farmers' association membership as a result of better access to market information, the transfer new farming technology, or discussions to help farmers solve their farming problems [23]. The policy instruments such as subsidies for seeds, pesticides, fertilizer, machinery, and extension officer assistance were not significant to the inefficiency effect. It was because those factors were not an essential determinant of technical inefficiency.

In brief, the government's approach to providing input subsidies was relatively ineffective because the beneficiary farmers are still facing technical inefficiency problems caused by their other farming management systems. The results of inefficiency revealed

that the government should consider encouraging farmers to join the farmers' association, which may influence a better efficiency level [47,48]. Figure 4 shows the summaries of the technical efficiency distribution of the studied farmers. There was significant variation in the level of efficiency among farmers, ranging from a very low 0.12–0.94. However, the mean efficiency level was 0.866. The distribution of efficiency shows that more than 50% of farmers have an efficiency level of more than 0.8, which is high.

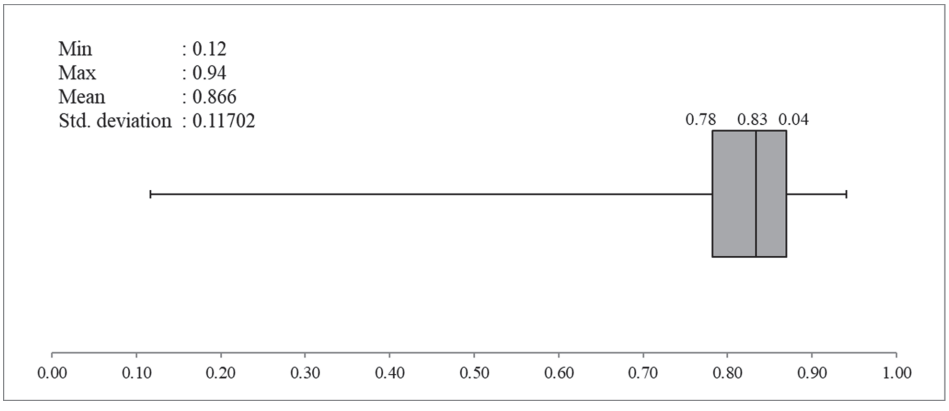

Figure 4. The distribution of farmers' technical efficiency level.

Hence, the policy instrument itself is not a significant determinant of efficiency. In a second step, this research examined the farmers' perspective to gain a better understanding of the real problems and farmers' behavior toward the *Upsus Pajale* program. According to Figure 5, the main reason farmers choose a specific crop is based on their habits, followed by profitability, irrigation system, marketability, price stability, and others. Habit became the farmer's first consideration because smallholder farmers are typically risk-averse [49,50]. Therefore, they prefer to plant a crop that is already familiar to them. Although rice, maize and soybeans might not be as profitable as other crops, these three strategic commodities are staple foods, particularly rice and maize, have stable market demand, and are consumed by family members. Consequently, farmers do not have to worry about an excess of supply in the market. Irrigation systems also became third indicators of the farmers considerations, which is in line with a study conducted by Haryanto et al. [44], who said that the irrigation infrastructure is essential for adequate water supply for rice farming. In terms of price stability, the Indonesian government provided a floor and ceiling price for rice; however, the results indicated that just 28.61% became a farmer's consideration. It is caused by the low price of rice set by the Indonesian government compared to the market.

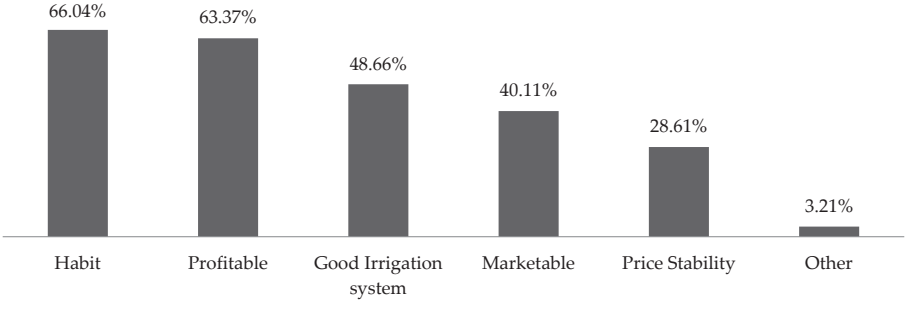

Figure 5. The reasons for farmers to choose their cultivated crops (percentage (%) refer to number of farmers from all the samples).

In Table 4, the study further revealed that about 56.1% of farmers agree that the program somehow helps solve some farming problems, such as adding extra capital. However, subsidies are not the main reason for farmers to choose to cultivate rice, maize, or soybeans. Particularly, about 50.3% of the farmers thought that planting those strategic crops was profitable, although they did not received any subsidies from the government. Moreover, the results also showed that the biggest agricultural problems that farmers face are mostly caused by pests (Figure 6).

Table 4. Farmers' perspective about the *Upsus Pajale*.

	Helped to Solve Farm Problem	Profitable although without Subsidies
strongly disagree	0.5%	2.4%
disagree	0.8%	9.4%
neutral	2.9%	29.4%
agree	56.1%	50.3%
strongly agree	39.6%	8.6%

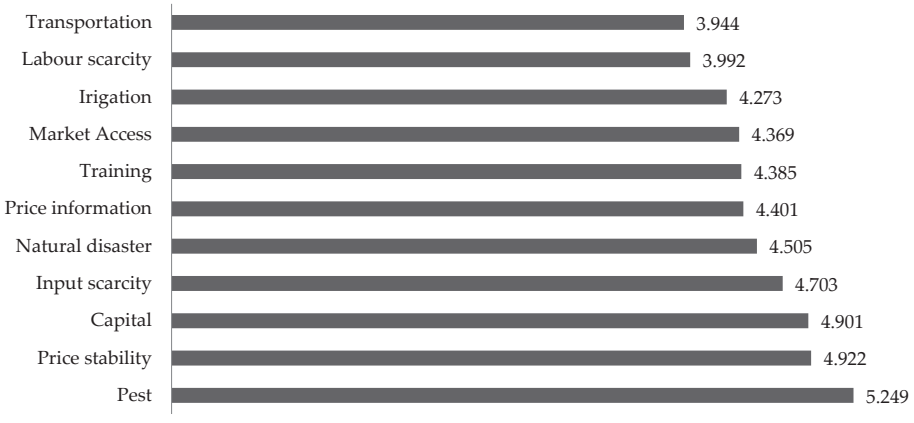

Figure 6. The agricultural problems for farmers.

In short, the results revealed that the *Upsus Pajale* program may be beneficial to farmers in terms of helping with farm capital. However, the government's approach to providing input subsidies was relatively ineffective because the beneficiary farmers are still facing technical inefficiency. Reform of the government spending policy from input subsidies toward higher spending on general services such as research and development for better seedling and pest management control seems more reasonable. The government is urged to take the initiative to encourage the establishment of farmers' association, addressing the provision of a well-functioning reach-out extension system that can provide farmers with the knowledge to obtain better information and new technology to use inputs properly and efficiently in order to increase yields. Furthermore, the farmers' association activities, e.g., sharing experience and demonstrating first-hand knowledge of pests, processing, and accessing the market, might be helpful to less-experienced farmers to improve their efficiency.

4. Conclusions and Policy Recommendation

The *Upsus Pajale* policy program's main goal was to increase production in order to achieve self-sufficiency in rice, maize, and soybeans, which would then improve national food security. The study used SFA to analyze the production efficiency of Indonesian farmers that received subsidies from the programs. The TE results showed that average efficiency level of the farmers was 0.866, indicating that it still has opportunity to

be increased to reach its maximum potential. The following factors were identified as significantly contributing toward improving farmers' efficiency, such as land size, seed cost, and labor cost, while fertilizer cost is not significant. The finding suggests that in order to increase the yield, farmers should use the larger land, and increase their seed and labor cost. The variance parameter was significantly different from zero, particularly the gamma value of 0.89, indicating that technical inefficiency in the farm management system was responsible for a portion of the inefficiency. In sum, the model of inefficiency effect showed that the farmers' age and joining the farmers' association were identified as significantly contributing towards decreasing of farmers' inefficiency. Meanwhile, the education level was positively improving the inefficiency level. Furthermore, none of the policy program instruments appear significant as an essential determinant factor for efficiency in order to increase production and accelerate productivity growth as the government wants to achieve.

Another purpose of the policy was to increase farmers' willingness to cultivate rice, maize, or soybeans. The study discovered that farmers' willingness to cultivate specific crops was typically based on habits and profitability rather than the government's subsidy schemes. Farmers agree that subsidies helped them increase farm capital, but it was not the primary factor in their decision to cultivate certain crops. The biggest agricultural problem that farmers faced in the study was pest problems. Therefore, to tackle these findings and problems, the government should focus on research and development to provide better seed and pest management control. The government should also take the initiative to encourage the establishment of farmers' associations, which could provide farmers with the knowledge to obtain better information and access the newest technology in order to increase yields.

5. Limitations and Future Recommendation

The authors realize that this research suffers from some limitations. First, the empirical model in terms of investigating the causes of technical inefficiency, such as the degree of market competitive pressure, various farm managerial characteristics, and other external factors such as climate changes, has not been included. Therefore, it will be more interesting if the future research can include those factors in the study. Second, the research data were gathered in 2016, which was the time farmers in the study area received the one-time subsidies (seed, chemicals, fertilizer, machinery, and training from agricultural extension officers) from the *Upsus Pajale* program; thus, this study would like to recommend that future studies update with the newest data about farmers' efficiency levels. Third, the study was conducted only in East Java, so it would be better if further research could discover many more provinces to provide more solid results and policy implications for better management purposes.

Author Contributions: Conceptualization, M.P. and W.-C.H.; methodology, M.P.; software, M.P.; validation, M.P. and W.-C.H.; formal analysis, M.P.; investigation, B.P.; resources, M.P. and B.P.; data curation, M.P.; writing—original draft preparation, M.P.; writing—review and editing, W.-C.H. and M.P.; visualization, M.P.; supervision, W.-C.H. and B.P.; project administration, B.P.; funding acquisition, M.P. and B.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to ethical reasons.

Acknowledgments: The authors are grateful to extension officer at UPTD Silo, UPTD Sumbersari and UPTD Ambulu, Jember, East Java for supporting to conduct the survey.

Conflicts of Interest: The authors declare no conflict of interest.

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Can Direct Marketing Increase Fishery Profitability and Environmental Quality? Empirical Evidence of Aquaculture Farm Households in Taiwan

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Abstract: Marketing strategies play a significant role in determining farm income. Although direct marketing has been proposed as an innovative way to improve producers' economic welfare, little is known about producers' adoption of direct marketing among aquaculture farms. This study examines the adoption of wholesaler markets, individual wholesalers or shippers, and direct marketing among aquaculture farms. In addition, we quantify the effects of the use of different marketing channels on fishery revenues, profits, and production inputs. A sample of 25,180 aquaculture family farms in Taiwan was drawn from the fishery census survey. After estimating the simultaneous equation system model, we find that the use of multiple marketing channels generates the highest fishery revenues, which highlights the importance of marketing channel diversity on selling fishery products. Moreover, we find a positive effect of direct marketing on fishery revenues and profits. We also find that the use of direct marketing can reduce the use of groundwater in aquaculture production. Since the decrease in groundwater use can mitigate the severity of land subsidence, this paper provides evidence that direct marketing can possibly provide a win-win strategy to improve fishery producers' revenues and environmental quality.

Keywords: direct marketing; marketing channels; aquaculture production; land subsidence; groundwater use

Citation: Lee, T.-H.; Liu, S.-Y.; Huang, C.-L.; Chang, H.-H.; Wang, J.-H. Can Direct Marketing Increase Fishery Profitability and Environmental Quality? Empirical Evidence of Aquaculture Farm Households in Taiwan. *Agriculture* **2023**, *13*, 1270. https://doi.org/10.3390/agriculture13061270

Academic Editor: Sanzidur Rahman

Received: 3 May 2023
Revised: 12 June 2023
Accepted: 16 June 2023
Published: 20 June 2023

1. Introduction

Marketing strategies are crucial for farms to sell their products, and they play a significant role in determining farm income. Small-scale family farms often rely heavily on traditional marketing channels such as wholesaler markets or individual distributors to sell their farm products [1]. While using traditional marketing channels may help family farms to manage market price uncertainty, the revenues generated from the final product sales are shared with the middlemen, potentially resulting in unequal distribution of the profits [2]. Direct marketing, also known as direct-sales-to-consumers marketing, has gained significant attention in recent years, and it has been considered an innovative marketing strategy to increase farm producers' revenues [3]. A considerable body of literature has been focused on direct-marketing strategies for crop farms, but not much research attention has been paid to fishery farms. An interesting question is whether the existing evidence found among crop farms in direct-marketing studies can be directly applied to aquaculture farm households. However, the answer is likely negative, as there

are significant differences between these two types of farms. For instance, fishery products have higher market values than crops, resulting in aquaculture farm households having less participation in non-farm labor markets compared to crop farm households. These differences in reliance on non-farm income sources may result in different tendencies to adopt marketing strategies. Furthermore, the nature of farm products is quite different when comparing crop and fishery farms. Consumers prefer fresh fishery products, making direct marketing arrangements a promising strategy for fishers to increase revenues by positioning themselves as both producers and dealers [3].

This paper contributes to the growing research interest in direct marketing by providing a quantitative analysis of aquaculture farm households' choice of marketing channels and producers' business performance using Taiwan as a case study. The objective of this study is to provide answers to the following questions: First, what is the role of the farm operator's socio-demographic characteristics, household conditions and production practices on the adoption of different marketing strategies of fishery farms? We focus on three marketing channels: the sale to wholesalers or distributors, those of wholesale markets, and those directly to consumers or restaurants. Second, what are the effects of the marketing channels on fishery farms' revenues, profits, and inputs used in fish production? Finally, since it has been well documented that aquaculture production has resulted in severe land subsidence problems by pumping groundwater during production in Taiwan, we examined the externality of producers' use of different marketing channels on the use of groundwater in aquaculture production. This part of the analysis sheds light on the relationship between marketing strategy and environmental sustainability because aquaculture production has resulted in serious pollution and land subsidence [4,5]. Due to the scarcity of fresh water in Taiwan, the over-pumping of groundwater in aquaculture production is common, making Taiwan a good study area for addressing this topic [6].

In Taiwan, there are 39,914 hectares of land used in aquaculture production. The number of family-type fish producers accounts for a large proportion of the fish producer population in Taiwan. The majority of fishery farms in Taiwan rely on traditional marketing channels by selling their products to individual wholesalers or wholesaler markets. The low amount of fish products makes individual wholesalers the major marketing channel for small fishery farms. In contrast, farms producing relatively larger amounts of fishery products are more likely to sell their products to wholesaler markets as they can have stronger bargaining power during price negotiation and lower transportation costs compared to small fishery farms [7]. In the past two decades, Taiwan's government encouraged fishery farms to use direct marketing channels by sell their products directly to individual consumers, restaurants or supermarkets. This active action on the promotion of direct marketing channels constitutes the response to the increased consumer concern for food safety. Direct marketing comes with the promotion of certificates or labels to ensure food safety in fishery production practices. For example, the Hazard Analysis Critical Control Point (HACCP) procedure has been implemented in Taiwan since 2004. The certificate of the HACCP requires producers to disclose detailed information, such as the use of water resources and medicine in fishery production [8]. Another popular food safety label in Taiwan is the Traceability Agricultural Product (TAP), which was implemented in Taiwan in 2007. The TAP system documents information that includes the name of the producers, the use of inputs in production, etc. [9]. Consumers can then use the QR code to trace the product records. Although consumers or restaurants are willing to pay a higher price to purchase fish products with food labels, the requirements of the food labels procedure generate additional costs to fishery farms [10].

The remaining part of this paper is organized as follows. We introduce the data and analytical framework in the next section. In what follows, we present the results and offer a discussion and the policy implications of these findings. In the final section, we conclude this paper and present the potential limitations of this paper and a direction for future studies.

2. Materials and Method

2.1. Data

To monitor the fishery industry in Taiwan, the Directorate-General of Budget, Accounting, and Statistics in Taiwan conducted face-to-face in-person interviews with all of the registered fish producers every five year since 1970. Given that the number of fishery farm households accounts for almost 98% of fish producers in Taiwan, this survey is a population-representative dataset of fish-producing households. In the survey, one principal operator in charge of fish production practices and business operation in each case is identified. The principle operator is responsible for reporting details on fish production and family characteristics. Information on fish production includes the revenues or sales value of fish products and the use of production inputs. Information on the socio-demographic characteristics of the principal operator, including gender, age, education and time allocation between self-family fish production and non-fishery work, was documented. In this study, we use the census survey conducted in 2015 [11] based on two reasons. First, the 2015 dataset is the latest fishery census survey. Second, this survey includes not only the standard questions as documented in early waves, but also several unique questions regarding the major marketing channels used by each fishery farm household to sell their products. So far, the 2015 census survey is the only data source that documents the use of marketing channels among fishery farms in Taiwan.

The 2015 census survey includes 38,800 fishery farm households. Each fishery farm household was asked to identify its main type of fishery production in 2015. In the survey, seven different types of fisheries are identified: the far sea fishery, offshore fishery, coastal fishery, inland fishery, marine aquaculture, inland brackish water aquaculture, and freshwater aquaculture. The last three categories belong to aquaculture production. Since this study focuses on the interaction between the use of marketing channels and fish production practices, especially the use of groundwater, we limit our sample to aquaculture farms, which includes the type of marine, inland brackish water, and freshwater aquaculture. In total, our sample consists of 25,192 aquaculture farm households. After subsequently deleting observations with missing values, our final sample included 25,180 aquaculture family farm households.

With respect to marketing channels, a survey question with multiple choices is documented. Each farm household was asked to select whether it engaged in the following marketing channels to sell their fishery products: wholesaler markets, fishery groups, individual shippers or wholesalers, supermarkets or hypermarkets, retailers, processing factories, restaurants, and individual consumers. According to the nature of the different marketing channels, we categorized these choices into three types of marketing channels. The first type is the wholesaler market, which included farm households that sold fishery products to wholesaler markets or fishery groups. The second type of marketing channel included those that sold fishery products to individual wholesalers, shippers or distributors. The third type of marketing channel included farms that sold products to supermarkets or hypermarkets, restaurants, or individual consumers. In the survey, each fishery farm household could select more than one type of marketing channel.

With respect to the economic performance of the aquaculture farm household, we specified a continuous variable to measure the sales value of self-produced fish products and other activities such as revenue from processing of self-produced fishery products and fishery tourism. Due to the limitation of the survey, revenue or income from non-fishery work is not included. The second variable is the profit of fish production, which is defined as the fishery revenue minus the expense of inputs used in fish production. These two variables are self-reported by the principle farm operator in each household, and both of them are measured in New Taiwan Dollars (NTD). Information on inputs used in fish production is also documented in the survey. We defined one continuous variable for the size of land used in aquaculture production and another continuous variable to indicate the number of hired labor used in aquaculture production. Although we did not have information on labor use and revenue from non-fishery work, the survey

documented whether the principle farm operator engaged in non-fishery work in the survey year. Accordingly, we defined a dummy variable to capture the extensive margin of the aquaculture farm in the non-fishery labor market. It has been well documented that aquaculture production is associated with the severe problem of land subsidence in Taiwan [4,6,12]. Since one research objective in this paper is to examine whether the use of marketing channels has any impact on environmental quality, we defined a dummy variable to indicate if the fishery farm used groundwater as the major water source in its aquaculture production.

We also specified several categories of explanatory variables associated with the choice of marketing channels and household income. For the demographic characteristics of the operator of the fishermen household, we defined five dummy variables to indicate if the operator was less than 29, 30–39, 40–49, 50–59, 60–69 or above 70 years of age. Five variables were specified to capture the operator's education level: illiterate, finished elementary school, junior high, senior high, and college or higher education. A dummy variable was also specified for the gender of the operator.

Several dummy variables are specified to indicate the major type of fish species. We defined a series of dummy variables by species in aquaculture cultivation: grouper, milkfish, tilapia, shrimp, oyster, clam, and other types of species. To control for family structure, we created three variables to measure household size and the ratio of adults living in the household. Two continuous variables were specified for the number of male and female family members, respectively. We also defined a variable to indicate the share of the number of adult members living in the family.

Since the use of marketing channels is assumed to be highly associated with the environmental condition of the fish markets, and since one of the marketing channels in this study is the wholesaler market, we defined three variables to capture the wholesaler market condition in the county in which each fishery farm is located. These include the average number of employees, land area, and monetary investments in equipment in the wholesale market. These variables are drawn from the Statistics Yearbook of fishery production in 2015 [13].

To understand the relationship between the engagement in marketing channels and the economic performance and production practice of aquaculture farms, we report the sample means of fishery revenue, profit, non-fishery work, number of hired labor, size of land in aquaculture production, and the use of groundwater in each combination of the three marketing channels in Table 1. For each outcome variable, we conducted an ANOVA test to see whether the sample means among the eight groups were statistically equal. As reported at the bottom of Table 1, the value of the F-tests ranged between 18.85 and 243.67. All of them reject the null hypothesis; this provides evidence that aquaculture farms using different marketing channels have different economic performances and inputs used in their fish production.

Table 1. Sample means of the outcome variables by marketing channels.

N	Wholesale Markets	Wholesalers	Direct Marketing	Revenue (TWD Million)	Profit (TWD Million)	Non-Fishery Work (0/1)	Hired Labor (Person)	Land (Hectare)	Ground-water (0/1)
1784	No	No	No	2.952	1.067	0.497	1.960	0.807	0.292
653	No	No	Yes	7.936	3.374	0.250	4.510	0.945	0.271
18,677	No	Yes	No	16.290	5.971	0.136	9.478	1.581	0.251
1631	No	Yes	Yes	14.129	5.249	0.142	9.641	1.828	0.149
550	Yes	No	No	16.476	6.529	0.229	7.480	1.603	0.275
158	Yes	No	Yes	14.519	5.473	0.196	6.703	1.691	0.222
1408	Yes	Yes	No	23.741	8.047	0.145	12.830	1.986	0.271
319	Yes	Yes	Yes	34.769	11.978	0.110	16.539	4.754	0.147
F-test				77.53	67.20	243.67	82.30	46.54	18.85

Note: The total sample size is 25,180. The null hypothesis of the F-test is the equality of the sample mean across groups. The *p*-values of all the tests are smaller than 0.001.

Among the 25,180 aquaculture farm households, we found that 18,677 aquaculture farms sell fish products to wholesalers or shippers only (74%), with 158 aquaculture farms that engage in wholesaler markets and direct marketing simultaneously, which has the lowest ratio of marketing channel engagement. Aquaculture farms that use all three channels have the highest value of fishery revenue (TWD 34.769 million) and profit (TWD 11.978 million). This group of farms also has a higher value regarding the number of hired labor and the size of land used in aquaculture production. In contrast, the participation rates in non-fishery work and groundwater use are lower than in other groups.

In Table 2, we report the definition and sample statistics of the outcome variables and all of the explanatory variables in the full sample, as well as the use of the three marketing channels. As reported in Table 2, it appears that the socio-demographical characteristics of the farm operator, fishery production condition and family characteristics differ among aquaculture farms that use different marketing channels. For example, the farm operators engaging in wholesaler markets have higher education levels. Compared to other groups of farms, 30% and 12.3% of the farm operators that engage in wholesaler markets had finished senior high school and college, respectively. With respect to fishery production condition, marine aquaculture farms are more likely to engage in direct marketing channels to sell their products compared to other groups of aquaculture farms. This observation shows that in order to identify the impact of the use of direct marketing on fishery revenue and profit, it is necessary to control for the differences in explanatory variables among aquaculture farms that used different marketing channels.

Table 2. Sample statistics of the selected variables.

		All		Wholesale Markets		Wholesalers		Direct Marketing	
Variable	**Definition**	**Mean**	**S.D**	**Mean**	**S.D**	**Mean**	**S.D**	**Mean**	**S.D**
Wholesaler markets	If use wholesaler markets (=1).	0.097	0.296	1.000	0.000	0.078	0.269	0.173	0.378
Wholesalers	If use wholesalers (=1).	0.875	0.331	0.709	0.454	1.000	0.000	0.706	0.456
Direct marketing	If use direct marketing (=1).	0.110	0.312	0.196	0.397	0.088	0.284	1.000	0.000
Revenue	Fishery revenue (TWD million).	15.632	32.092	22.947	48.164	16.873	31.943	15.071	35.822
Profit	Fishery profit (TWD million).	5.711	11.792	8.052	18.259	6.137	11.776	5.596	14.689
Non-fishery work	If operator has a non-fishery job (=1).	0.167	0.373	0.163	0.369	0.136	0.343	0.167	0.373
Hired labor	Number of hired labor (person).	9.043	16.173	11.710	21.018	9.807	16.563	9.057	18.565
Groundwater	If groundwater is the main water source in fish production (=1).	0.248	0.432	0.253	0.435	0.244	0.429	0.182	0.386
Land	Land area in fish production (hectare).	1.589	3.893	2.243	8.279	1.671	4.043	1.949	7.903
Age_29	If operator age $\leq$29 (=1).	0.006	0.075	0.004	0.064	0.006	0.075	0.004	0.063
Age_3039	If operator age 30–39 (=1).	0.042	0.201	0.036	0.187	0.043	0.203	0.032	0.175
Age_4049	If operator age 40–49 (=1).	0.140	0.347	0.143	0.350	0.142	0.349	0.130	0.336
Age_5059	If operator age 50–59 (=1).	0.281	0.450	0.311	0.463	0.281	0.449	0.294	0.456
Age_6069	If operator age 60–69 (=1).	0.280	0.449	0.284	0.451	0.278	0.448	0.298	0.457
Age_70	If operator age $\geq$70 (=1).	0.251	0.434	0.222	0.416	0.251	0.433	0.243	0.429
Illiteracy	If operator is illiterate (=1).	0.088	0.283	0.058	0.234	0.087	0.282	0.071	0.256
Elementary	If finished elementary school (=1).	0.313	0.464	0.269	0.444	0.316	0.465	0.339	0.473
Junior high	If finished junior high school (=1).	0.234	0.423	0.250	0.433	0.235	0.424	0.230	0.421
Senior high	If finished senior high school (=1).	0.265	0.441	0.300	0.458	0.264	0.441	0.256	0.437
College	If college or higher education (=1).	0.101	0.302	0.123	0.328	0.097	0.296	0.104	0.306
Male	If male operator (=1).	0.856	0.351	0.861	0.346	0.857	0.350	0.873	0.333
HHSIZE_male	Male household members (person).	1.806	1.112	1.858	1.107	1.796	1.105	1.840	1.121
HHSIZE_female	Female household members (person).	1.558	1.196	1.628	1.236	1.546	1.192	1.576	1.207
Ratio_adult	Ratio of adult household members.	0.946	0.133	0.947	0.131	0.947	0.133	0.944	0.134
Type_marine	If marine aquaculture (=1).	0.094	0.292	0.055	0.228	0.104	0.305	0.137	0.344

Table 2. *Cont.*

Variable	Definition	All		Wholesale Markets		Wholesalers		Direct Marketing	
		Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
Type_brackish water	If inland brackish water aquaculture (=1).	0.543	0.498	0.531	0.499	0.556	0.497	0.362	0.481
Type_fresh water	If inland freshwater aquaculture (=1).	0.363	0.481	0.415	0.493	0.340	0.474	0.502	0.500
Aqua_grouper	If grouper aquaculture (=1).	0.079	0.270	0.115	0.320	0.082	0.274	0.078	0.269
Aqua_milkfish	If milkfish aquaculture (=1).	0.239	0.427	0.304	0.460	0.253	0.435	0.229	0.420
Aqua_tilapia	If tilapia aquaculture (=1).	0.163	0.370	0.184	0.387	0.134	0.341	0.175	0.380
Aqua_shrip	If shrimp aquaculture (=1).	0.128	0.334	0.129	0.335	0.134	0.341	0.108	0.311
Aqua_oyster	If oyster aquaculture (=1).	0.088	0.283	0.045	0.207	0.093	0.291	0.157	0.364
Aqua_clam	If clam aquaculture (=1).	0.136	0.343	0.043	0.203	0.145	0.352	0.053	0.225
Aqua_other	If other types of fish (=1).	0.168	0.373	0.181	0.385	0.159	0.366	0.198	0.399
City	If located in a city area (=1).	0.398	0.489	0.557	0.497	0.393	0.488	0.453	0.498
Mkt_employee	Number of employees in wholesaler markets (person).	54.447	24.878	59.788	25.307	55.243	24.700	48.175	20.673
Mkt_land	Land area of wholesaler markets (hectare)	2.565	1.633	2.752	1.724	2.618	1.631	2.121	1.223
Mkt_equip	Investment in equipment (TWD 1000/m^2).	3.758	5.542	5.362	6.970	3.653	4.801	4.790	8.629
N		25,180		2435		22,035		2761	

2.2. Econometric Model

Several econometric issues have to be addressed in the specification of the empirical model. First, the choices of marketing channels are made by the aquaculture farms, so the problem of endogeneity bias has to be considered. Endogeneity bias may arise if the decision to choose marketing channels and the fishery revenue or other outcomes are correlated due to unobserved common factors, such as the risk preference of the farmers. It is likely that aquaculture farmers who are more averse to risk may invest less in farm equipment. Therefore, this type of farmer may have lower revenue than the others. Since the risk attitude of the farmer is not observed by the researcher, potential endogeneity bias can occur. The second issue is related to the selection of the approach. The framework of our analysis lies in the treatment effect or program evaluation literature. In this strand of literature, how to deal with endogeneity bias is the core issue. Several methods including the propensity score matching, difference-in-differences, and regression discontinuity have become popular in program evaluation literature (for a review of each model, see [14,15]). In this study, we did not apply these methods as they are more appropriately applied to a case with a single treatment. Even though multiple treatment models have been proposed, some strict restrictions have been imposed in these models. For example, the multi-valued treatment effect model proposed in Cattaneo [16] extends the propensity score method to the case of multiple treatments, although all of the treatments have to be mutually exclusive. Moreover, the identification condition of this model relies on the selection-on-observables assumption, which cannot be empirically tested. To cope with endogeneity bias, we follow the traditional simultaneous system framework to specify a four-equation simultaneous equation system:

$$\begin{gathered} D^*_{1i} = \alpha_1 + \beta_1{}' X_i + \gamma_1{}' Z_i + \varepsilon_{1i} \\ D^*_{2i} = \alpha_2 + \beta_2{}' X_i + \gamma_2{}' Z_i + \varepsilon_{2i} \\ D^*_{3i} = \alpha_3 + \beta_3{}' X_i + \gamma_3{}' Z_i + \varepsilon_{3i} \\ Y_i = \alpha + \lambda_1 \times D_{1i} + \lambda_2 \times D_{2i} + \lambda_3 \times D_{3i} + \beta' X_i + \varepsilon_i \\ D_{ki} = 1 \text{ if } D^*_{ki} > 0;\ D_{ki} = 0 \text{ if } D^*_{ki} \le 0;\ k = 1,2,3 \end{gathered} \tag{1}$$

where $D^*_{1i,}$ D^*_{2i} and D^*_{3i} are the unobserved latent variables for the use of wholesaler markets, individual wholesalers or shippers, and direct marketing of the *i*th aquaculture farm household, respectively. D_{ki} is the observed binary choice variable of each decision

(k = 1, 2, 3). Y_i is the outcome variable for fishery revenue, profit, or production inputs. The vector X_i includes explanatory variables associated with the socio-demographic characteristics of the farm operator, family and production condition, and Z_i includes the condition of the wholesaler markets in the county in which each fishery farm is located (see the full list of the variables in Table 2). $\alpha, \alpha_1, \alpha_2, \alpha_3, \beta, \beta_1, \beta_2, \beta_3, \gamma_1, \gamma_2, \gamma_3, \lambda_1, \lambda_2, \lambda_3$ are the parameters of interest. $\varepsilon_1, \varepsilon_2, \varepsilon_3, \varepsilon$ are random errors that follow a multivariate normal distribution with means zero, and the variance–covariance matrix is given by $\sum = \begin{bmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} \\ \rho_{12} & 1 & \rho_{23} & \rho_{24} \\ \rho_{13} & \rho_{23} & 1 & \rho_{34} \\ \rho_{14} & \rho_{24} & \rho_{34} & \sigma^2 \end{bmatrix}$, where the correlation coefficient between any two choices (ρ) captures the joint nature of these decisions. These correlation coefficients capture the relationships among the four equations due to unobserved common factors. Therefore, testing whether these parameters are statistically close to zero provides justification for the potential endogeneity bias problem. The parameters $\lambda_1, \lambda_2, \lambda_3$ capture the effects of the use of each marketing channel on the outcome variable. In the empirical analysis, Equation (1) is jointly estimated using the conditional mixed process proposed in Roodman [17], which utilizes the Geweke, Hajivassiliou, and Keane (GHK) algorithm to consistently estimate the full model.

With respect to model identification, Equation (1) is theoretically identified by the recursive nature between the use of marketing channels and the outcome variable, and the parametric assumption of the error terms. A recursive structure is ensured by the fact that the choice of the marketing channels affects the outcome variable, and not vice versa. This justification of the one-way causal relationship has also been discussed in the theoretical framework in the previous section. Unlike the instrumental variable approach, it is not necessary to have any exclusion variables to identify the system of equations [18]. Nevertheless, it is generally considered good empirical practice to include some exclusion variables to increase the statistical power underlying the empirical estimation. In this paper, we use the three variables to reflect the capacity and size of the wholesaler markets at the county level as exclusion variables (the variables Z_i in Equation (1)). These variables are assumed to be directly correlated with the likelihood of aquaculture farms to engage in the wholesaler markets in the local area.

3. Results

We report our results in several tables. Table 3 reports the marginal effects of the explanatory variables in the simultaneous equation system model for the choice of marketing channels. In Table 4, we report the impacts on farm revenues, profit, and inputs associated with aquaculture production from the use of different marketing channels. For the sake of presentation, we only report the estimated coefficients of the marketing channels. In Table 5, we report the results of the statistical tests in regard to model specification.

Table 3. Estimated marginal effects of the use of marketing channels.

	Wholesale Markets		**Wholesalers**		**Direct Marketing**	
Variable	**Mar. Eff**	**S.E**	**Mar. Eff**	**S.E**	**Mar. Eff**	**S.E**
Age_3039	0.009	0.028	−0.008	0.030	0.006	0.031
Age_4049	0.018	0.027	−0.016	0.028	0.039	0.029
Age_5059	0.025	0.027	−0.023	0.028	0.051	0.029
Age_6069	0.026	0.027	−0.027	0.028	0.052	0.029
Age_70	0.018	0.027	−0.029	0.029	0.043	0.030
Elementary	0.001	0.008	0.028 ***	0.008	0.010	0.008
Junior high	0.016	0.009	0.018 **	0.009	−0.004	0.009
Senior high	0.011	0.009	0.016	0.009	0.001	0.009

Table 3. *Cont.*

Variable	Wholesale Markets		Wholesalers		Direct Marketing	
	Mar. Eff	S.E	Mar. Eff	S.E	Mar. Eff	S.E
College	0.008	0.010	−0.014	0.010	0.011	0.005
Male	0.001	0.006	0.003	0.006	0.013 **	0.006
HHSIZE_male	0.003	0.002	−0.004 **	0.002	0.001	0.002
HHSIZE_female	0.004 **	0.002	−0.007 ***	0.002	0.001	0.002
Ratio_adult	0.014	0.016	0.023	0.017	−0.020	0.016
Aqua_grouper	0.014	0.008	0.061 ***	0.009	−0.043 ***	0.009
Aqua_milkfish	0.004	0.006	0.100 ***	0.007	−0.038 ***	0.007
Aqua_tilapia	0.009	0.007	−0.061 ***	0.006	−0.012	0.007
Aqua_shrip	−0.015 **	0.007	0.079 ***	0.008	−0.027 ***	0.007
Aqua_oyster	−0.050 **	0.023	0.144 ***	0.022	−0.044 **	0.019
Aqua_clam	−0.057 ***	0.009	0.105 ***	0.008	−0.117 ***	0.009
Type_marine	0.010	0.022	−0.045 **	0.021	0.116 ***	0.019
Type_brackish water	−0.001	0.005	−0.004	0.005	0.043 ***	0.005
City	0.094 ***	0.006	−0.089 ***	0.006	0.096 ***	0.006
Mkt_employee	0.003 ***	0.000	−0.001 ***	−0.000	0.001 ***	0.000
Mkt_land	0.046 ***	0.003	−0.041 ***	−0.004	−0.051 ***	0.004
Mkt_equip	0.001 **	0.000	−0.001 ***	−0.000	0.000	0.000

Note: *** and ** indicate significance at the 1% and 5% level.

Table 4. Estimated results of fishery revenues, profits, and input use in fishery production.

Variable	Fishery Revenue						Fishery Profit						Land in Fishery Production					
	(A1) Coef.		S.E	(A2) Coef.		S.E	(B1) Coef.		S.E	(B2) Coef.		S.E	(C1) Coef.		S.E	(C2) Coef.		S.E
Wholesaler markets	1.58	***	0.515	1.29	***	0.343	0.45	***	0.108	0.39	***	0.098	0.07	***	0.008	0.27	***	0.086
Wholesalers	1.32	***	0.113	1.39	***	0.118	0.46	***	0.038	0.50	***	0.040	0.08	***	0.008	0.44	***	0.084
Direct marketing	1.07		0.519	0.68		0.358	0.07		0.040	0.03		0.018	0.04	***	0.008	0.33	**	0.154
Direct marketing × wholesaler markets				0.05		0.029				0.13	**	0.051				0.05		0.031
Direct marketing × wholesalers				0.04	**	0.016				0.21	***	0.059				0.11	***	0.016
Direct marketing × markets × wholesalers				0.09	**	0.033				0.32	**	0.123				0.09	**	0.036
	Non-fishery work						**Hired labor in fishery production**						**Groundwater in fishery production**					
	(D1)			(D2)			(E1)			(E2)			(F1)			(F2)		
Wholesaler market	−0.06	***	0.008	−0.01	***	0.002	0.429	***	0.035	1.25	***	0.079	0.01		0.013	0.00		0.014
Wholesalers	−0.02	***	0.007	−0.03	***	0.002	0.102		0.052	0.74		0.391	0.02	**	0.010	0.01		0.011
Direct marketing	0.04	***	0.007	0.02	***	0.002	0.133	***	0.033	1.12		0.065	−0.04	***	0.007	−0.04	***	0.013
Direct marketing × wholesaler markets				−0.00		0.003				−0.21		0.107				0.01	**	0.002
Direct marketing × wholesalers				0.02	***	0.002				0.18	**	0.061				0.00	**	0.001
Direct marketing × markets × wholesalers				0.01		0.038				0.12		0.124				−0.00		0.003

Note: All of the explanatory variables are included in each equation. The full list of the explanatory variables is found in Table 2. *** and ** indicate significance at the 1% and 5% level.

Table 5. Results of the LR tests on model specification.

Outcome Equation	H^0: $\rho = 0$ [#1]	H^0: $Z = 0$ [#2]
Fishery revenue	111	243
Fishery profit	120	252
Land in fish production	121	251
Number of hired labor	109	241
Non-fishery work	231	238
Groundwater use	641	287
Critical value	$x^2(6, 0.01) = 16.8$	$x^2(9, 0.01) = 21.67$

Note: We conducted LR tests in the model without the inclusion of the interaction terms among marketing channels. [#1] H^0: all of the correlation coefficients are zero. [#2] H^0: the coefficients of the three variables related to wholesaler markets in the local area are zero.

3.1. The Determinants of the Choice of Marketing Channels

In the main model, we estimate a simultaneous equation system model with fishery revenue as the outcome variable by using the conditional mixed process method. We report the full estimation results in Table A1 in the Appendix A and the results of the calculated marginal effects of the explanatory variables in Table 3. As reported in Table 3, fishery production practice, the socio-demographic characteristics of the principle operator, and household conditions are associated with the aquaculture farms' choices of marketing channels. With respect to the socio-demographic characteristics of the operator, it is evident that operator's education is an important factor regarding the choices of marketing channels. Operators with higher education levels are more likely to engage in direct-sales-to-consumers marketing channels. For example, operators with a college degree or higher education are more likely to sell products directly to consumers or restaurants by 1.1 percentage points compared to the reference group of the operators who are illiterate, all things being equal. The gender of the operator also matters in relation to the choice of marketing channels. The results show that male operators are more likely to sell their products directly to consumers or restaurants by 1.3% compared to their female operator counterparts. Moreover, we found that fish species are important when determining the choices of marketing channels of aquaculture farms. For example, compared to the reference group of farms harvesting other types of fish species, groper aquaculture farms are more likely to engage in wholesalers by 6.1%, *ceteris paribus*.

3.2. The Impact of Marketing Channels on Economic Performance

In addition to fishery revenue, we estimate the simultaneous equation system model for five other outcome variables, including fishery profits, number of hired labor, size of land in production, non-fishery work, and groundwater use. Table 4 reports the estimated coefficients of the three marketing channels for each outcome equation. For each outcome variable, we specify and estimate two slightly different models. In addition to the explanatory variables, the first model only includes the separate variables of each marketing channel, while the second model includes the additional three interaction terms of the three marketing channel variables. The inclusion of these interaction terms can help to test whether the use of multiple marketing channels affects the outcome variables, especially the fishery revenues and profits.

As reported in columns (A1) in which fishery revenue is specified as the outcome variable, the use of wholesaler markets, wholesalers, and direct marketing all contribute positively to fishery revenue. Other things being equal, aquaculture farms that use wholesaler markets, individual wholesalers, and direct marketing channels have higher fishery revenues by TWD 1.582, TWD 1.322, and TWD 1.075 million, respectively, compared to their non-user counterparts. By further including the interaction terms of the use of marketing channels, the results reported in column (A2) show that using multiple marketing channels can further increase fishery revenue. For example, aquaculture farms that rely only on direct marketing have higher revenues by TWD 1.075 million compared to their non-user

counterparts of direct marketing. However, farms engaging in both direct marketing and wholesalers markets have higher revenues by TWD 0.046 million compared to those that simply rely on direct marketing channels. We find a similar pattern of the results for fishery profits (see columns (B1) and (B2)).

3.3. The Impact of Marketing Channels on Inputs Used in Aquaculture Production

We report the effects of the use of marketing channels on land size, engagement in non-fishery work, the amount of hired labor and the use of groundwater in columns (B1)–(F2), respectively. The results show that the use of marketing channels also increases the use of land in aquaculture production. Other things being equal, the use of wholesaler markets, individual wholesalers and direct marketing increase the size of production land by 0.075, 0.082 and 0.045 hectares compared to their non-user counterparts, respectively. In addition, using multiple marketing channels to sell fishery products results in more land used in aquaculture production. The consistency of the results in land use and fishery revenues may reflect the fact that land is an essential input in aquaculture production, and the increase in the size of aquaculture production can generate higher fishery revenue. Similarly, we find a positive effect of marketing channel use on the number of hired workers in fish production. The results regarding the use of hired labor are interesting. As reported in columns (E1), the magnitude of the effects is smaller for aquaculture farms that sold their products only to individual wholesalers (the coefficient is 0.102), and the largest effect is found for those that sold products to wholesaler markets (the coefficient is 0.429). These results may reflect the nature of the shipping process in that fishery products sold to wholesaler markets usually require a significant amount of transportation-related labor. Aquaculture farms that sell their products to individual wholesalers or distributors are not responsible for product shipping; therefore, they use less labor compared to the group of farms that sell products to wholesaler markets or directly to consumers.

As discussed in the conceptual framework, we find that the use of marketing channels is significantly associated with the aquaculture farms' engagement in the non-fishery labor market. However, different effects are evident for the different use of marketing channels. Results reported in column (D1) show that farms that sold products to wholesaler markets and individual wholesalers are less likely to engage in non-fishery labor market by 6.3 and 2.2 percentage points, respectively, compared to their counterparts of non-users. In contrast, we find a positive effect of direct marketing on non-fishery work. Aquaculture farms that sell products directly to consumers or restaurants are more likely to work off the farm by 3.7 percentage points, all things being equal.

To link our analysis to environmental quality, we conducted an analysis to examine the effects of the choice of marketing channels on groundwater use. The results are reported in columns (F1) and (F2). The results point to a negative effect of the use of marketing channels on groundwater use for aquaculture farms that sold products to wholesalers or wholesaler markets. In contrast, as reported in column (F1), aquaculture farms that sold products directly to consumers or restaurants are less likely to use groundwater as the main water resource in aquaculture production by 3.7 percentage points compared to their non-user counterparts, all things being equal.

3.4. Results of the Statistical Tests Regarding Model Specification

We conducted two statistical tests to show the validity of the model specification. The first test is used to justify the specification of the simultaneous equation system. We conducted the LR test to check whether the correlation coefficients are jointly equal to zero (i.e., $\rho_{12} = \rho_{23} = \rho_{24} = \rho_{13} = \rho_{34} = \rho_{14} = 0$). The second LR test is used to check the statistical power of the exclusion variables. As indicated earlier, the model is theoretically identified, but the inclusion of the exclusion variables can increase the statistical power in regard to the empirical estimation. We conducted these tests for the six simultaneous equation systems.

As reported in Table 5, the test values of the LR test range between 109 and 641 under the null hypothesis that all of the correlation coefficients are zero. Given that the critical value is 16.8 ($x^2(6, 0.01) = 16.8$), we reject the null hypothesis for all six models; this result justifies the use of the simultaneous equation system. With respect to the exclusion variables, the results of the LR test are between 238 and 287; all of them are larger than the critical value ($x^2(9, 0.01) = 21.67$). These results provide statistical evidence regarding the validity of these exclusion variables.

4. Discussion

Several interesting findings are revealed in this study, and we offer discussions on them in this section. We found that fishery revenues or profits are higher for aquaculture farms that involve multiple marketing channels. This result echoes the findings of the agricultural marketing literature, which has pointed out that given the nature of highly perishable agricultural products, optimizing sales likely requires the flexibility of combining different marketing channels capable of accepting alternative sizes and types of products. Moreover, the use of multiple marketing channels can help to reduce the price risk and increase farm revenues [19]. The policy implications inferred from this finding are straightforward. From the view of fishery producers, using multiple marketing channels can help to spread the operational risks. Therefore, the government should provide assistance or subsidies to increase the use of multiple marketing channels among fishery producers. In contrast, simply promoting a single marketing channel is not the best way to increase fishery producers' revenue.

Although the Taiwanese government has promoted the use of direct marketing among fishery producers, the adoption rate is still low among aquaculture farms. Most of the fishery farms in Taiwan still rely on traditional marketing channels by selling their products to wholesalers or distributors, which may reflect the fact that wholesale channels typically have a better ability to move large quantities of produce quickly and usually at a lower transportation cost than through direct channels. In contrast, direct marketing often requires more customer interaction and time requirements from the producers. The lower participation rate of direct marketing may also reflect the strict regulation of the safety of fish products when fish products are directly sold to consumers or restaurants.

Previous studies have highlighted the significance of marketing channels for fishery producers' income [20–26]. For instance, Ahmed et al. [23] examined the impact of a government-funded project aimed at promoting direct marketing among prawn producers in Bangladesh. They found that the marketing chain of prawn products became shorter, with a significant reduction in intermediaries after the implementation of the program. Direct marketing can also enhance producers' revenues since it provides them with a reasonable and stable purchasing price. Gomez and Maynou [24] studied fish producers' attitudes toward direct sales and the certification of origin labeling scheme labels in Catalonia and the Balearic Islands. They found that setting minimum fair ex-vessel prices would reduce the negative perception of the fishers regarding price competition. Wetengere [25] examined the constraints to the marketing of farmed fish in inland Tanzania. The authors highlighted the importance of market engagement on fishers' profits, with fish products sold to middlemen and shipped to urban cities having higher producer prices on average. Geng [26] used survey data to study the determinants of aquatic farmers' participation in marketing channels in Jiangsu Province, China. The authors found that farmers' social networks could increase their participation in modern marketing channels such as direct marketing. In contrast to the previous studies, we find that using direct marketing alone cannot generate the largest profits of fishery farms. This may reflect the strict requirement of food safety on fishery products in Taiwan. In Taiwan, restaurants usually require certificates to ensure food safety, such as the label for Hazard Analysis Critical Control Point (HACCP). The HACCP reveals information on fish production, such as the use of water resource and medicine, to ensure the safety of fish products sold to consumers. Although consumer willingness to pay for fish products with HACCP labels is higher than those

without labels [10], the required information disclosure process in aquaculture production increases the entry barriers for farms to apply for HACCP.

With respect to the determinants of the aquaculture farms that engage in direct marketing, we find that the human capital of the operator as well as the fish production characteristics are important factors. Aquaculture farms whose operators have higher education are more likely to adopt a direct marketing strategy. This result is consistent with the findings of prior studies on technology adoption in agriculture, which point out that educated farm workers are more likely to adopt new technologies because they have a better ability to acquire information on the new technology [27,28]. Interestingly, we also find that aquaculture farms that use direct marketing channels are more likely to engage in non-fishery work. This finding may reflect the importance of social connection in non-fish job markets on the adoption of direct marketing. For example, the successful operation of direct marketing usually requires access to, or the search for, potential customers [26]. In our case, aquaculture farms that have off-fishery business work may have more opportunities to search for potential consumers or restaurants. In this regard, a positive correlation between off-farm work and the adoption of direct marketing is expected.

Our results also indicate that aquaculture farms engaging in direct marketing are less likely to use groundwater as the main water resource in their aquaculture production. This result again echoes the strict requirement of HACCP labels on fishery products sold to individual consumers due to the concern for safe food. Many aquaculture farms use groundwater in production; however, pumping groundwater is illegal in Taiwan since groundwater use is highly associated with the land subsidence problem. Therefore, those fishery farms that heavily rely on groundwater may encounter difficulty in receiving a food safety certificate. In terms of policy, our finding is important from the standpoint of policy since we provide supporting evidence that policies that aim to increase aquaculture farms' adoption of direct marketing have an unintended effect on environmental quality, such as land subsidence. More specifically, our results provide an interesting case study that direct marketing can prove to be a win-win strategy to secure fishery revenue; it also has the potential to improve environmental quality.

Finally, we summarize the contributions of our study to previous studies on marketing channels as follows. Firstly, unlike previous studies that focused solely on a single marketing channel, such as direct marketing, this study examined both direct marketing and traditional wholesale channels. As far as we know, this is one of the first papers to compare the effects of these two distinct marketing channels on fishery economic outcomes. Secondly, prior studies that explored the relationship between marketing channels and fishery income often used simplistic descriptive statistics that failed to account for endogeneity bias due to fishery farms' marketing channel choices. This study used econometric analysis to control for differences in the socio-demographic characteristics of the operator, household, and production conditions among various groups of aquaculture farms. As a result, it provides a more accurate assessment of the impacts of different marketing channels on fishery outcomes. Thirdly, the data used in this study are unique. They relied on a census survey of aquaculture farm households in Taiwan, which provides more objective policy implications. Finally, this study examined the interactions between aquaculture farms' marketing strategies and groundwater use. Since aquaculture production is highly associated with land subsidence caused by groundwater over-pumping, this analysis has implications for environmental sustainability by examining the impact of marketing channels on groundwater use.

5. Conclusions

A direct marketing strategy has been seen as an innovative way to improve the income of fishery farms. This study contributes to this research topic by examining its effect on aquaculture farms' fishery revenues, profits, and inputs used in aquaculture production between the use of traditional marketing channels and direct marketing. We drew a unique population-based dataset of aquaculture farm households from the census

survey in Taiwan. To quantify the effect of the use of marketing channels on the economic outcomes of aquaculture farms, we estimated a simultaneous equation system model with three choices of marketing channels and one outcome variable. After controlling for the socio-demographic characteristics of the farm operator, household and production condition, we found a significant and positive effect between direct marketing and fishery revenue and profit. Moreover, we found that revenue and profit are higher for farms that engage in multiple marketing channels. In addition, aquaculture farms engaging in direct marketing are less likely to use groundwater as the main water source in production.

Although this paper reveals several interesting findings, some caution is indicated. Perhaps one of the notable limitations is the use of the 2015 dataset. As indicated clearly in the paper, the census survey was conducted every five years, and the latest version is in 2015. Moreover, the 2015 census is the only available dataset that documents the use of marketing channels of fishery farms. Since the outbreak of COVID-19 that occurred in 2021 has disrupted the whole world, it may have affected the fishery industry as well. For example, it has been found that consumers' demand for online food shopping [29] and transportation and production costs of fishery products increased during the pandemic period [30]. This may increase the use of the marketing channels of fishery farms. Although we cannot obtain updated data to empirically accommodate the effect of COVID-19, we believe the main findings of this study can still stand during the COVID-19 period. The most significant result of this study indicates that the use of multiple marketing channels enhances fishery farm income in that using more than one channel to sell fishery products can help to spread the business operational risks of the farm. Given that transportation costs and market price became more volatile after COVID-19, the use of multiple channels may become more important to fishery farms to cope with these risks. Using the data after COVID-19 may strengthen our findings. This research topic can be better examined by future studies when the historical data are available in other countries or areas.

In addition to the issue of COVID-19, other caveats may remain. For example, in accordance with the information documented in the census survey, we can only define a binary variable for the use of direct marketing. If the data on product quantity sold to each marketing channel were available, we could measure the effect of the intensive margin of each marketing channel on fishery revenue. Moreover, direct marketing can be performed in several ways, such as online and offline sales. If more detailed data are available, we could further distinguish the impact on fishery revenue by different forms of direct marketing. Due to the limitation of data availability, we only know whether or not the farm operator worked in non-fishery work. If the information on the type of off-farm work was available, we could measure different forms or intensities of social networking. Finally, the amount of water used in fish production for each aquaculture farm was not documented in our data. This type of information could provide better insights into the link between water use and land subsidence. Regardless of these potential drawbacks, this paper is one of the first to provide an analytical framework and a case study to highlight the importance of marketing channels on fishery revenue and environmental quality.

Author Contributions: Conceptualization, T.-H.L., S.-Y.L., H.-H.C. and J.-H.W.; methodology, T.-H.L., S.-Y.L. and C.-L.H.; software, S.-Y.L.; validation, H.-H.C. and J.-H.W.; formal analysis, S.-Y.L. and C.-L.H.; writing—original draft preparation, T.-H.L., S.-Y.L. and C.-L.H.; writing—review and editing, H.-H.C. and J.-H.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The individual data of the census survey can be accessed with permission from the Council of Agriculture in Taiwan.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Estimation results of the simultaneous equation system (the outcome variable is fishery revenue).

	Wholesaler Markets			Wholesalers			Direct Marketing			Fishery Revenue		
Variable	**Coef.**		**S.E**	**Coef.**		**S.E**	**Coef.**		**S.E**	**Coef.**		**S.E**
Wholesaler markets										1.582	***	0.515
Wholesalers										1.322	***	0.113
Direct marketing										1.075		0.519
Age_3039	0.054		0.173	−0.046		0.162	0.033		0.180	3.120		2.757
Age_4049	0.111		0.166	−0.086		0.156	0.227		0.173	1.881		2.649
Age_5059	0.156		0.165	−0.123		0.155	0.298		0.172	2.910		2.633
Age_6069	0.160		0.165	−0.150		0.156	0.306		0.173	3.479		2.647
Age_70	0.110		0.167	−0.158		0.157	0.250		0.174	1.495		2.674
Elementary	0.007		0.050	0.154	***	0.043	0.056		0.046	2.190	***	0.778
Junior high	0.098		0.056	0.101	**	0.050	−0.025		0.053	1.508		0.908
Senior high	0.069		0.058	0.088		0.051	0.008		0.055	3.708	***	0.933
College	0.052		0.064	−0.076		0.057	0.066		0.034	7.764	***	1.063
Male	0.004		0.035	0.018		0.033	0.077	**	0.035	0.889		0.598
HHSIZE_male	0.016		0.012	−0.024	**	0.011	0.003		0.012	1.120	***	0.206
HHSIZE_female	0.023	**	0.010	−0.038	***	0.010	0.005		0.010	0.774	***	0.184
Ratio_adult	0.086		0.098	0.128		0.091	−0.119		0.095	2.012		1.670
Aqua_grouper	0.087		0.048	0.334	***	0.050	−0.250	***	0.052	14.063	***	0.911
Aqua_milkfish	0.026		0.040	0.548	***	0.038	−0.222	***	0.039	−11.254	***	0.686
Aqua_tilapia	0.056		0.041	−0.332	***	0.033	−0.069		0.038	−13.831	***	0.698
Aqua_shrip	−0.096	**	0.042	0.433	***	0.041	−0.160	***	0.042	−7.782	***	0.728
Aqua_oyster	−0.307	**	0.146	0.793	***	0.121	−0.258	**	0.113	−22.142	***	2.414
Aqua_clam	−0.355	***	0.059	0.576	***	0.046	−0.687	***	0.051	−10.638	***	0.834
Type_marine	0.060		0.135	−0.245	**	0.116	0.684	***	0.112	7.097	***	2.338
Type_brackish water	−0.007		0.029	−0.020		0.028	0.251	***	0.030	−1.010	**	0.509
City	0.583	***	0.036	−0.490	***	0.032	0.561	***	0.033	−1.533	***	0.520
Mkt_employee	0.016	***	0.001	−0.003	***	0.001	−0.005	***	0.001			
Mkt_land	0.287	***	0.020	−0.224	***	0.020	−0.301	***	0.021			
Mkt_equip	0.005	**	0.002	−0.006	***	0.002	−0.000		0.002			
Constant	−2.057	***	0.205	0.787	***	0.191	−1.311	***	0.209	0.098		3.440
σ										30.649		16.844
ρ_{12}										−0.378	**	0.150
ρ_{13}										0.227	***	0.017
ρ_{14}										−0.118		0.089
ρ_{23}										−0.338	**	0.153
ρ_{24}										−0.020		0.021
ρ_{34}										0.028		0.020
Log-likelihood	−144,948											

Note: *** and ** indicate significance at the 1% and 5% level.

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Digital Revolution and Employment Choice of Rural Labor Force: Evidence from the Perspective of Digital Skills

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Abstract: The practical implementation of the employment promotion effect of the digital economy is closely linked to rural laborers' digital skills (DS). Therefore, this study uses the Mprobit model to empirically test the impact of DS on rural labor employment choices. The results show that: (1) the acquisition of DS by the rural labor force significantly increases the rate of off-farm employment and entrepreneurship but has no significant effect on farm employment, with work skills having the most significant positive impact on the rural labor force off-farm employment and online business skills having the most significant positive impact on rural labor force entrepreneurship. (2) The mechanism test reveals that DS influences the employment choices of the rural labor force by alleviating the information access constraint and financing constraints faced by rural labor. (3) Heterogeneity analysis shows that males and rural laborers in rich regions can benefit from entrepreneurship. In contrast, females and low-skilled and rural laborers in middle and poor regions can benefit more from off-farm employment. Our findings provide empirical evidence on effectively cultivating DS to increase the diversity of employment choices for the rural workforce and highlight the importance of improving DS.

Keywords: digital economy; digital skills (DS); employment choice; off-farm employment; entrepreneurship

Citation: Wang, X.; Huang, Y.; Zhao, Y.; Feng, J. Digital Revolution and Employment Choice of Rural Labor Force: Evidence from the Perspective of Digital Skills. *Agriculture* **2023**, *13*, 1260. https://doi.org/10.3390/agriculture13061260

Academic Editors: Hung-Hao Chang, Pei-An Liao and Jiun-Hao Wang

Received: 21 April 2023
Revised: 11 June 2023
Accepted: 15 June 2023
Published: 18 June 2023

1. Introduction

In recent years, with the development of the digital economy, the rapid sinking of the digital economy in rural areas, represented by the Internet and e-commerce, has not only had a comprehensive impact on the production, life, and ecology of the rural workforce but has also had a profound impact on the employment market of the rural workforce [1–5]. According to the Digital China Construction and China Taobao Village Study Report, as of December 2021 there were 284 million Internet users in rural China, with a 57.6% Internet penetration rate. Moreover, the size of the digital economy reached 45.5 trillion yuan in 2018, with 191 million jobs created in the digital economy. The number of digital economy jobs is expected to reach 379 million by 2025. The digital economy can offer new opportunities for the full employment of the vast rural workforce.

It is worth noting that while the digital economy has brought huge employment dividends to all, it has placed higher demands on the DS for the workforce [6]. Scholars have carried out considerable research on the definition of digital skills, but no consensus has yet been reached. Digital skills, according to Eshet [7], are the abilities of individuals to perform tasks such as producing, living, and learning in a digital environment. From a developmental standpoint, Martin et al. classified residents' digital skills into three

stages [8]. The first stage is the capacity to utilize digital tools and devices correctly, while the second is the ability to use digital tools and devices to access digital resources. The third stage is the ability to use digital tools to innovate and create new knowledge and resources. Due to China's lagging digital skills education system, rural residents' ability and awareness to use digital technologies to innovate expertise and resources are currently low. As a result, digital skills are currently characterized as micro-subjects' attitudes and abilities to use digital tools and devices correctly and appropriately, to utilize digital resources, to learn new knowledge, and to communicate socially with others in the evolving digital environment.

Even though digital devices such as smartphones are now widely available in rural China, the digital skills of China's rural labor force remain relatively poor. According to the data from the "Survey and Analysis Report on Digital Literacy in Rural China in the Context of Rural Revitalization Strategy", released by the Informatization Research Center of the Chinese Academy of Social Sciences in 2021, the digital skills gap between urban and rural residents in China is evident, with the average score of urban residents being 56.3 out of 100. The average score of rural residents is 35.1, a difference of up to 21.2 points, and rural residents' average score is 37.5% lower than urban residents. Rural residents have a digital literacy score of only 18.6, notably lower than other occupational groups and 57% lower than the overall population average. According to the survey, as China's rural infrastructure is rapidly digitizing and networking, the central conflict of the "digital divide" between urban and rural areas in the new era is changing from infrastructure to digital literacy and skills. In this context, the Chinese government has placed a high value on efforts to improve the overall DS of the population. As early as 2018, the "Guidance on Stabilizing and Expanding Employment in the Development of the Digital Economy" stated unequivocally the importance of "upgrading the digital skills of new farmers and new subjects", with the goal of "driving more workers to shift and improve their employment quality". In 2022, the 14th Five-Year Plan specifically advocated strengthening digital skills education and training for all people and popularizing and improving citizens' DS.

To improve rural residents' DS, it is required not only to develop network infrastructure and bridge the "access gap" but also to pay attention to network training methods and scientifically determine training contents. We should concentrate on assisting the rural labor force in mastering software such as smart agriculture and improving the rural labor force's digital application abilities. For example, giving rural workers hands-on chances such as live e-commerce training, teaching rural laborers how to utilize new media tools to capture market information promptly, and teaching rural laborers how to use mobile phone software for digital marketing to help agricultural products enter the city. At the same time, promoting and explaining digital security knowledge and skills to rural labor in batches is vital to compensate for digital security weaknesses and strengthen the rural workforce's digital skills. Digital skills are a kind of human capital, and the carrier of its function is digital technology. For the rural workforce, digital technology use is divided into two categories: accessibility and depth of use, with the former reflecting differences in access opportunities and the latter reflecting differences in digital skills [9]. Most existing studies have explored the impact of the digital technology access opportunity gap on rural labor force employment [5,10,11]. However, few have looked at the impact of rural labor force DS acquisition on their employment choices from the perspective of participants' capabilities.

This paper examines the impact of the rural labor force's acquisition of DS on their employment choices using data from the China Family Panel Studies (CFPS) from 2014 to 2018. This study contributes to the related literature in three ways. First, existing studies have primarily examined the impact of digital economy development on rural labor force employment from the perspective of application effects such as Internet use, digital infrastructure, and digital technology application [12–15]. However, minimal research has been carried out to investigate the impact of DS on the employment choices of rural labor. We are among the first to discuss the rural workforce's DS on their employment choices

from the perspective of participants' abilities and broadening the exploration of the digital economy on rural labor employment research. Second, in terms of transmission mechanisms, prior research focused primarily on the impact of individual natural endowments, such as human capital and social capital, on rural labor force employment. This paper completes the impact of DS on the role of various financing channels and information accessibility from the perspective of individual financing channels and information accessibility, emphasizing that improving financial and information accessibility in the context of the digital economy also requires complementary DS. Third, regarding policy significance, this paper provides empirical evidence and path recommendations for how policymakers can effectively cultivate DS to drive diverse employment in the rural workforce.

The rest of the paper is structured as follows. Section 2 includes literature reviews and research hypothesis. Section 3 specifies our variables, data, and estimation methods. Section 4 presents our empirical results. Further analyses, such as mechanism and heterogeneity, are exhibited in Section 5. The last section concludes.

2. Literature Review and Research Hypothesis

2.1. Literature Review

Current scholarly research on the impact of rural labor force employment is primarily concerned with non-farm employment and the factors that influence non-farm employment, such as human capital, social capital, and demographic and household characteristics [16–19]. Human capital theory suggests that human capital is the most critical factor influencing rural laborers' employment and career development. Improving human capital levels can increase workers' labor-market competitiveness and thus promote rural laborers' non-agricultural employment transfer. Kurosaki and Khan used micro panel data to investigate human capital's effects on non-farm employment. The findings showed that education significantly increases the rural labor force's non-farm employment rate and wages of the rural labor force [20]. Luan et al. found that education plays an essential role in increasing the non-farm income of the rural labor force [21]. The social capital theory believes that social capital plays an essential role in the job search process of rural laborers. China is a traditional "geo-society" and "human society". Rural "human affection" can have various positive effects, including trust, dependence, and mutual aid. It is also conducive to transmitting and gathering knowledge and raising rural laborers' employment or self-employment rate [22]. Morise found that social capital contributes to the off-farm employment rate of the rural labor force and, thus, access to off-farm wages [23]. Liang et al. argued that social capital, as a social resource embedded in interpersonal networks, can facilitate the dissemination of employment information and promote rural labor's non-farm employment [24]. Finally, regarding demographic and household characteristics, Cheng and Pan found that rural laborers' individual and household characteristics considerably impacted their non-agricultural employment [25].

Many studies have been conducted to investigate the impact of digital economy development on rural laborer employment, but a consistent conclusion has yet to be reached. Two main views are presented: The first is the "creation effect", which argues that developing the digital economy will boost rural labor force employment, as Isley and Low explored the relationship between broadband and employment rates during April and May 2020 in rural U.S. counties. They discovered that broadband availability and wired broadband adoption significantly impacted rural employment rates [26]. Atasoy examinexd the impact of broadband internet access expansion from 1999 to 2007 on labor market outcomes across the United States and discovered that gaining access to broadband services in a county is associated with a 1.8 percentage point increase in the employment rate [1]. Hjort and Poulsen estimated the effect of Internet access on employment in Africa using the gradual arrival of submarine Internet cables on the coast and maps of the terrestrial cable network. The results showed that Internet access significantly increases African employment [27]. Meanwhile, Bruno also found that the digital economy increases employment demand, mainly through increased productivity, industrial sector innovation, and technology diffu-

sion [23]. However, some scholars have argued against this, arguing that the development of the digital economy will lead to a decline in labor demand by reducing the value of current jobs, shortening the life cycle of jobs, and increasing the price of human capital, thus putting forward a second "substitution theory" view. Through theoretical analysis, Lishchuk et al. pointed out that the development of the digital economy mainly leads to the reduction of labor demand through increased productivity, the application of intelligent and innovative technologies, and the change of industrial structure [28]. From the perspective of skill differences, Acemoglu and Restrepo discovered significant differences in the impact of the digital economy on the labor force with different skills, increasing the demand for high-skilled labor and decreasing the demand for low-skilled labor [29].

In summary, previous studies have contributed to our understanding of the impact of digital economy development on rural labor force employment. However, the above literature ignores the premise of Amartya Sen's theory of "feasible ability". The individual must have the corresponding feasible abilities to achieve functional activities, provided the material conditions are met [30]. The rural labor force's lack of digital skills makes it likely to be excluded from the digital employment system, particularly in the context of the existing "same network and same speed" society in China [31]. Numerous studies have shown that digital skills, as a "gateway" to employment, can significantly impact an individual's chances of getting a job, promotion, or salary increase and workplace employability, productivity, and efficiency [32]. Therefore, while testing the impact of digital economy development on rural labor force employment choices, the rural labor force's digital skills acquisition should be considered. Thus, from a participant ability standpoint, this paper supplements the micro-reality evidence and mechanical testing of the impact of rural labor's acquisition of digital skills on their employment choices. It enriches the research on the employment aspects of the digital economy.

2.2. Research Hypothesis

There are two main reasons for the positive impact of DS on rural labor force employment choices. On the one hand, DS can increase the diversity of employment. According to human capital theory, human capital is essential to rural laborer employment. DS significantly accumulates human capital [13]. Rural laborers mastering DS can use digital platforms for online learning to improve their professional skills and reverse their attitudes toward risk, increasing their probability of diverse and high-quality employment [33]. At the same time, acquiring DS can help the rural workforce access a broader range of economic opportunities. According to the Organization for Economic Cooperation and Development's (OECD) Digital Economy Outlook 2019, rural labor can work more flexibly and conveniently through online platforms rather than being employed by a single formal employer, significantly increasing the possibility of multiple employment for rural labor and effectively improving rural employment options for the labor force [34].

On the other hand, DS has a significant spatial spillover effect on rural labor entrepreneurship, effectively promoting local rural labor entrepreneurship and significantly impacting rural labor entrepreneurship in neighboring areas [35]. According to resource-based theory, human, physical, and social capital influence entrepreneurial success. First, as an essential component of human capital, DS significantly impacts entrepreneurs' entrepreneurial capabilities, identifying entrepreneurial opportunities and integrating entrepreneurial resources, which play an essential role in driving entrepreneurial behavior. Second, rural laborers with higher DS can use the Internet to break down geographical barriers in traditional social networks, broaden the radius of social interactions, and open up new "friend circles" and social circles, which can not only provide emotional and financial support for rural laborers, but can also help to improve the accuracy and timeliness of information acquisition, boost their competitive advantages, and thus increase the entrepreneurship rate [36]. In contrast, an increase in the entrepreneurship rate can help to increase new jobs and employment opportunities, significantly improving rural laborers' employment options. All of the above analyses suggest that promoting the cultivation

of DS can help rural laborers participate more extensively and effectively in the digital economy, which in turn helps to increase the diversity of employment options for rural laborers. As a result, the following hypothesis is proposed in this paper.

Hypothesis 1. *Mastery of DS can significantly improve employment options for the rural workforce.*

According to entrepreneurial resource endowment theory, resource endowment conditions significantly influence individual entrepreneurship. Numerous empirical studies have also shown that initial wealth accumulation affects individual entrepreneurial activities. Financing constraints can prevent rural laborers from crossing the entrepreneurial capital threshold or achieving the optimal amount of capital investment, inhibiting their entrepreneurial decisions [37–39]. When rural laborers are equipped with DS, on the one hand, they can increase the financing channels of rural laborers through e-commerce platforms, Alipay, and the micro-lending function of mobile payment providers to alleviate financing constraints and improve financial accessibility [40,41]. On the other hand, the effective accumulation of social capital can be accomplished by expanding and maintaining relationship networks through online communication platforms, enriching rural laborers' financing channels [42]. According to information effect theory, entrepreneurial capabilities include identifying entrepreneurial opportunities, controlling entrepreneurial risks, and reducing transaction costs. The ability of rural laborers to access information is more critical in identifying entrepreneurial opportunities in rural areas where information dissemination channels are more limited, and the cumulative effect of information generated by information access will positively impact rural laborers' employment decisions [43,44]. With the implementation of the "digital countryside" strategy in recent years, the Internet and e-commerce have rapidly declined in rural areas. When rural laborers have specific digital skills, they can communicate via the Internet and e-commerce platforms, which can help improve their information dissemination efficiency and broaden the scope of information dissemination, alleviating information constraints and increasing the likelihood of identifying entrepreneurial opportunities. Based on this, this paper puts forward the following hypothesis:

Hypothesis 2. *Mastering DS affects the rural labor force's employment choice by relieving financing and information acquisition constraints.*

The mechanism analysis is presented in Figure 1.

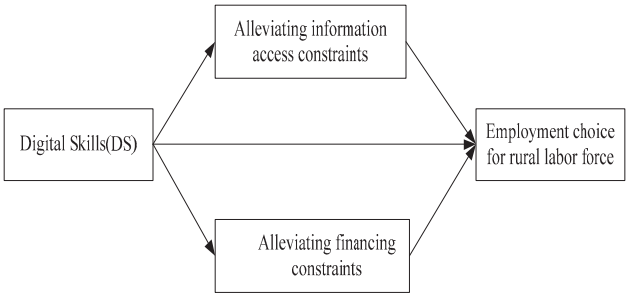

Figure 1. Mechanism analysis of DS influencing employment choice for rural labor force.

3. Data and Methods

3.1. Data Source

The empirical analysis is based on the 2014–2018 China Family Panel Studies (CFPS) dataset. This paper investigates the impact and mechanism of DS on rural labor employment choices. The survey data can provide detailed and reliable research data support.

CFPS data is a nationwide sample survey project covering 25 provinces, autonomous regions, and municipalities under the central Government of China. The database contains individual and household socio-economic information and more detailed information on household economic activities, social interactions, and demographics. Considering the research objectives of this paper, individual-level, household-level, and province-level data are to be used. Data from the CFPS 2014–2018 database are to be matched with provincial-level data in turn, and then laborers living in rural areas and aged 18–64 years old are screened out as research subjects. The missing data of key variables and data with obvious outliers were excluded, and the last panel data of 10,679 samples for three years were obtained.

3.2. Model, Variable Selection, and Description

3.2.1. Model

The following econometric model is used in this study to investigate the impact of DS on rural labor employment choice:

$$P(y_i = j \mid x_i) = \frac{\exp(b_j x_i')}{\sum_{k=1}^{j} \exp(b_k x_i')} \tag{1}$$

In Equation (1), $P(y_i = j \mid x_i)$ represents the possibility of employment choice of the rural labor force, x_i represents the influencing factors on rural labor force's i choice of employment, and b_k represents the regression coefficient value. Then, assuming $y_i = k$ as a reference variable, Equation (1) can be transformed into Equation (2):

$$P(y_i = j \mid y = korj) = \frac{P(y = j)}{P(y = k) + P(y = j)} = \frac{\exp(x_i' b_j)}{1 + \exp(x_i' b_j)} \tag{2}$$

The corresponding relative risk ratio is Formula (3):

$$\frac{P(y = j)}{P(y = k)} = \exp(x_i' b_j) \Rightarrow \ln\left(\frac{P(y = j)}{P(y = k)}\right) = x_i' b_j \tag{3}$$

Putting all variables into Equation (3), the employment choice model Equation (4) is obtained:

$$\ln\left(\frac{P_j}{P_k}\right) = \alpha_0 + \alpha_1 \gamma_i + \sum_{m=2}^{n} a_m X_i + \varepsilon \tag{4}$$

Among them, P_j represents the employment status of the jth interviewee. In this paper, P_1 represent self-employed agriculture (SEA), P_2 represents agricultural employment (AE), P_3 represents non-farm employment (NFE), and P_4 represents entrepreneurship (EP), respectively assigned values of 1, 2, 3, and 4. γ_I represents the digital skills possessed by the i respondent. X represents a series of control variables, including variables of individual characteristics, family characteristics, and regional characteristics.

3.2.2. Variables Selection and Description

(1) Dependent variables. The dependent variable in this paper is employment choice. The employment choice variable is primarily based on the type of work answered by the individuals in the questionnaire, and the types of employment are divided into four categories: self-employed agriculture (SEA) = 1, agricultural employment (AE) = 2, non-farm employment (NFE) = 3, and entrepreneurship (EP) = 4. According to the CFPS questionnaire, a rural laborer is characterized as SEA if they work for themself/their own family in agriculture. The rural laborer is classified as engaged in AE if employed by another individual or company and works in agriculture.

(2) Independent variables. The independent variable in this paper is digital skills (DS), which are identified as both the access and use levels. First, at the access level, the rural

workforce is judged to have the basis for using digital tools and devices based on whether they use computers or cell phones. If yes, 1 is assigned; otherwise, 0 is assigned. Second, at the use level, the frequency of individuals' use of digital functions in the China Household Tracking Survey (CFPS) database reflects digital skills, which include "frequency of using the Internet for learning, working, socializing, entertainment, and business activities", with seven levels of frequency ranging from "never" to "almost every day" and a score of 0–6 for "never" to "almost every day". Factor analysis was used to reduce the dimensionality of the 5 dimensions, and principal component analysis was used to extract common factors with eigenvalues greater than 1. A total of 3 common factors were extracted, and their cumulative variance contribution rate reached 77%, indicating that they can reflect the changes in the 5 dimensions. Because of the negative values of the factor scores, they were transformed into values between 0 and 6 according to the standard scores. The KMO values were approximately 0.690. The significant *p*-values of Bartlett's test were all 0.000, indicating a good correlation between the dimensions and the validity of the factor analysis results.

(3) Control variables. To avoid the problem of omitted variables as much as possible, referring to the previous literature [41,45–47], the control variables in this paper include individual characteristics, household characteristics, and regional characteristics. Specific variables are described below, and the summary statistics of these variables are shown in Table 1.

Table 1. Variable definition and descriptive statistics.

Variables	Variables Definitions	Mean	SD
Employment choice	SEA = 1, AE = 2, NFE = 3, EP = 4	2.481	1.075
DS	Obtained from the factor analysis of the frequency of multi-dimensional functions of digital technology	3.486	1.396
Gender	Male = 1, Female = 0	0.427	0.495
Age	Age value	34.47	10.15
Age^2	Square of age	1291	761.2
Education	Years of education	8.887	3.827
Health	Healthy categorical variables 1–5	2.644	1.117
Marital status	Married = 1, other = 0	0.787	0.409
Family size	Total family size	4.763	2.010
Family upbringing burden	Number of children to total family size ratio	0.201	0.198
Industrial structure	The ratio of output value of the primary industry to GDP	0.096	0.037
Regional GDP per capita	Logarithm of regional GDP per capita	10.74	0.381
Urbanization rate	Urbanization rate	55.55	10.10

Source: Based on CFPS data in 2014, 2016, and 2018; sample size is 10,679.

4. Results and Discussion

4.1. Impact of DS on Rural Labor Force Employment Choices: Main Results

Table 2 shows the estimated impact of DS on rural labor force employment choices. The Mprobit model's explained variables are four types of employment, and the regression results use SEA as the reference group. The first three columns of Table 2, Columns (1) to (3), do not include the fixed effects of time and region. The results demonstrate that the DS coefficients are insignificant in AE, while they are all statistically significant at the 1% level in NFE and EP. The last three columns of Table 2, Columns (4) to (6), include the fixed effects of time and region. The results show a robust effect that DS can significantly increase NFE and EP but not AE. Furthermore, DS are more likely to promote NFE than EP. On the one hand, most of the information posted on Internet-based information recruitment platforms is for off-farm jobs, so even if the rural labor force masters DS, it will have little impact on AE. On the other hand, with the application of digital technologies in recent

years, such as the Internet, the rural labor force's efficiency in job search and information acquisition in the labor market has improved. As a result, the rural labor force's acquisition of DS significantly promotes NFE and EP. However, the promotion effect between the two differs because EP necessitates a higher level of human capital and digital skills from the rural labor force than NFE.

Table 2. The impact of DS on rural labor force's employment choice.

Variables	(1) AE	(2) NFE	(3) EP	(4) AE	(5) NFE	(6) EP
DS	0.0003	0.0259 ***	0.0153 ***	0.0001	0.0303 ***	0.0211 ***
	(0.0009)	(0.0050)	(0.0031)	(0.0008)	(0.0047)	(0.0031)
Gender	0.0090 ***	0.0433 **	0.0313 ***	0.0092 ***	0.0424 **	0.0306 ***
	(0.0031)	(0.0170)	(0.0089)	(0.0030)	(0.0167)	(0.0082)
Age	0.0022	−0.0186 ***	0.0127 ***	0.0021	−0.0169 ***	0.0146 ***
	(0.0015)	(0.0032)	(0.0038)	(0.0014)	(0.0032)	(0.0039)
Age^2	−0.0000	0.0001 ***	−0.0002 ***	−0.0000	0.0001 ***	−0.0002 ***
	(0.0000)	(0.0000)	(0.0001)	(0.0000)	(0.0000)	(0.0001)
Education	−0.0020	0.0807 ***	0.0046	−0.0020	0.0783 ***	0.0018
	(0.0012)	(0.0067)	(0.0049)	(0.0012)	(0.0059)	(0.0051)
Health	0.0011	−0.0071	0.0036	0.0011	−0.0066	0.0052 *
	(0.0011)	(0.0051)	(0.0030)	(0.0011)	(0.0050)	(0.0029)
Marriage	−0.0022	−0.0846 ***	0.0580 ***	−0.0029	−0.0858 ***	0.0527 ***
	(0.0059)	(0.0175)	(0.0163)	(0.0060)	(0.0182)	(0.0152)
Family size	0.0007	−0.0102 ***	0.0047 *	0.0007	−0.0098 ***	0.0049 **
	(0.0007)	(0.0029)	(0.0026)	(0.0007)	(0.0030)	(0.0025)
Family upbringing burden	−0.0059	0.0302	−0.0263	−0.0062	0.0292	−0.0214
	(0.0068)	(0.0207)	(0.0205)	(0.0070)	(0.0207)	(0.0201)
Industrial structure	0.0130	−1.5316 ***	−0.0781	−0.0071	−1.6343 ***	0.1350
	(0.0714)	(0.3955)	(0.2795)	(0.0737)	(0.3364)	(0.2432)
Regional GDP per capita	0.0208 **	0.0488	0.0623	0.0153	0.0756	0.0539
	(0.0094)	(0.0661)	(0.0470)	(0.0097)	(0.0669)	(0.0448)
Urbanization rate	−0.0002	−0.0001	−0.0023	−0.0004	−0.0013	−0.0026
	(0.0003)	(0.0034)	(0.0015)	(0.0003)	(0.0036)	(0.0019)
Time FE	No	No	No	Yes	Yes	Yes
Region FE	No	No	No	Yes	Yes	Yes
Observations	10,679	10,679	10,679	10,679	10,679	10,679

Notes: The coefficients in the table are marginal effects rather than regression coefficients; the standard errors in brackets are clustered at the provincial level; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.2. Impact of Different Dimensions of DS on Rural Labor Force's Employment Choice

Table 3 further disaggregates DS to examine the impact of different dimensions of DS on rural laborers' employment choices. Mou et al. [48] classified DS into five dimensions: digital learning skills, digital social skills, digital entertainment skills, digital business skills, and digital work skills, and the five dimensions of DS were regressed using a panel Mprobit model. The findings showed that, compared to SEA, rural laborers' acquisition of digital learning, social, work, and business skills had insignificant effects on individuals' choice of AE. However, all significantly increased the proportion of NFE and EP among rural laborers. Work skills had the most significant positive effect on NFE among rural laborers, and business skills had the most significant EP promotion effect. This suggests that a rural labor force with good job skills has better access to decent jobs and a higher proportion of NFE. In contrast, a rural labor force with online business skills can alleviate credit constraints, increase financial availability to promote EP, and thus increase EP. Meanwhile, the rural labor force acquisition of recreational skills reduces the proportion of AE and increases the proportion of NFE and EP. The main reason for this is that, on the one hand, rural areas lack recreational and leisure facilities and have lower levels of human capital than urban areas. At the same time, online entertainment and social interaction are more attractive to rural residents, making them more likely to engage in online games and online

social platforms, squeezing out their working time and reducing the proportion employed in agriculture. On the other hand, compared with urban residents, rural laborers with limited social capital are more likely to be constrained by access to information resources. The acquisition of recreational and social skills assists rural laborers in expanding their "circle of friends" and social circle based on kinship to enhance social capital, among which the information and trust functions of social capital can significantly increase the probability of NFE and thus squeeze out the proportion of AE and increase the proportion of NFE and EP.

Table 3. Impact of different dimensions of DS on the employment of rural labor force.

Variables	(1) AE	(2) NFE	(3) EP
Digital learning skills	0.0004	0.0060 ***	0.0025 *
	(0.0006)	(0.0018)	(0.0015)
Digital social skills	0.0006	0.0132 ***	0.0041 ***
	(0.0005)	(0.0025)	(0.0013)
Digital work skills	0.0010	0.0267 ***	0.0080 ***
	(0.0007)	(0.0022)	(0.0022)
Digital entertainment skills	−0.0010 **	0.0058 *	0.0105 ***
	(0.0005)	(0.0033)	(0.0016)
Digital business skills	−0.0000	0.0181 ***	0.0223 ***
	(0.0010)	(0.0038)	(0.0020)
Control variables	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Observations	10,679	10,679	10,679

Notes: The coefficients in the table are marginal effects; the control variables are consistent with Table 2; the standard errors in brackets are clustered at the provincial level; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.3. Robustness Check

(1) Endogeneity problem. In order to test and solve the endogeneity problem of the above model due to factors such as omitted variables and reverse causality, the instrumental variables method is used in this study to overcome the possible effects of the above problem. The conditional mixed process (CMP) method proposed by Roodman was used to re-estimate the relationship between DS and rural labor force employment choices, drawing on the studies of Tian et al. and Zhang et al. [49,50]. It is worth noting that an appropriate instrumental variable must be found regardless of whether the instrumental variable method or CMP estimation is used. According to Zhou and Fan [36], whether or not families have computers in the 2014 CFPS questionnaire was chosen as an instrumental variable for DS. First, the relevance hypothesis is met because whether or not families have computers is a requirement for using the Internet and mastering DS in general, satisfying the relevance condition. Second, the exogenous criterion is met because there is no correlation between whether or not families have computers and the occupation preferences of the rural labor force. Therefore, the instrumental variables in this paper are selected more reasonably. The CMP model is used to construct a set of equations for estimation, and columns (1) and column (2) in Table 4 are the results of estimation using the probit model and Mprobit model, respectively. From column (1), the coefficient of the effect of household computer ownership on DS is 0.3443 and is significantly positive at the 1% level, indicating that it meets the hypothesis of correlation. From column (2), the effect of DS on NFE and EP is still significant and positive after using the instrumental variable, except for the non-significant effect on AE, suggesting that the acquisition of DS by rural laborers still significantly increases the likelihood that rural laborers will choose NFE and EP. In addition, in terms of the coefficients, the absolute value of the coefficient of DS becomes larger for each employment type after using the instrumental variables method, indicating that the effect of DS acquisition on NFE is underestimated due to the endogeneity

problem. However, the conclusion that the acquisition of DS can significantly contribute to the diversification of employment options in the rural labor force is still robust.

Table 4. Test results of the CMP model using instrumental variables.

Variables	(1) DS	AE	(2) NFE	EP
DS	-	0.0002	0.0488 ***	0.0160 *
		(0.0027)	(0.0158)	(0.0097)
IV: Whether or not family have computer	0.3443 ***	-	-	-
	(0.0890)			
Control variables	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Observations	2212		2212	

Notes: The coefficients in the table are marginal effects; the control variables are consistent with Table 2; the standard errors in brackets are clustered at the provincial level; * $p < 0.1$, *** $p < 0.01$.

(2) Omitted variable test. In the baseline regression model, this paper controls for some individual and household-level covariates that affect the employment choices of rural laborers as much as possible. However, some unobservable variables still bias the estimation results of the model. Therefore, drawing on Oster's study uses the model's results with observable variables to assess the impact of potentially missing unobservable variables on the model results [51]. Specifically, the main principle of this approach is to observe how many times the unobserved factors are the observed factors in order to have a significant effect on the initial estimation results by measuring the model in this paper. The results are shown in Table 5. First, from the result in the first row, we can see that the 95% confidence interval into which the actual calculation of numerical skill β^* falls and which does not contain 0 indicates that no unobserved variables are as important as those already observed to impact the empirical results. Second, from the result in the second row, we can see that the measurement of δ values suggests that, even if the model has the problem of omitting unobservable variables, the effect of that omitted variable is at least 2.1307 times greater than that of the observable variable in terms of having an impact on the empirical results of the model, which is less likely to occur. Therefore, it is difficult for the omitted variable to bias the empirical results, so the core findings of this paper are more robust and credible.

Table 5. Omitted variable test results.

Variables	Testing Method	Judgment Criteria	Actual Calculation Result	Whether to Pass Test
DS	(1)	$\beta^* = \beta^*(R_{max}, \delta) \in (0.1179, 0.1611)$	0.1395	Yes
	(2)	$\beta > 1$	2.1307	Yes

(3) Replace explanatory variables. In this section, DS is characterized by the degree of importance rural workers place on the various functions presented by digital devices, also known as digital attitudes. Based on the data available, this paper uses the "importance of work, study, social, recreational and business activities" to reflect rural workers' attitudes toward using digital technology online, with five levels of importance ranging from very unimportant to very important. The same principal component analysis was used to extract common factors with eigenvalues greater than one and convert them into values between 0 and 6 according to the standard score. The panel Mprobit model is then used for regression analysis. The results are shown in Panel A of Table 6. The results show that the effect of digital attitudes on AE is not significant but still significantly increases the proportion of NFE and EP among rural laborers, which is consistent with the baseline regression results, indicating that the core findings of this paper are more robust.

Table 6. Robustness tests of DS on employment choices of rural labor force.

Panel A: Replace Core Explanatory Variables			
	AE	**NFE**	**EP**
Digital attitude	0.0007	0.0259 ***	0.0195 ***
	(0.0012)	(0.0038)	(0.0024)
Control variables	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Observations	10,679	10,679	10,679
Panel B: Exclude Regions with More Developed Internet			
DS	0.0007	0.0321 ***	0.0201 ***
	(0.0008)	(0.0049)	(0.0028)
Control variables	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Observations	9193	9193	9193
Panel C: Replace Panel Mlogit Model for Regression			
DS	−0.0007	0.0485 ***	0.0212 ***
	(0.0007)	(0.0051)	(0.0032)
Control variables	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Observations	10,679	10,679	10,679

Notes: The control variables are consistent with Table 2; the standard errors in brackets are clustered at the provincial level; *** $p < 0.01$.

(4) Excluding regions with more developed Internet. Given the regional unevenness of Internet development, regions with higher levels of Internet development have more developed digital network infrastructure and training. As a result, the digital technology adoption behavior of rural laborers in these regions, as well as the frequency of activities involving digital technology, are not entirely determined by the independent choices of micro subjects but are heavily influenced by the external development environment, characterizing DS solely in terms of the frequency of specific behaviors biasing the estimates. According to the document "Operation of the Internet and Related Services Industry" issued by the Ministry of Industry and Information Technology, it is clearly stated that the current level of Internet business development in five provinces, namely Guangdong, Beijing, Shanghai, Zhejiang, and Fujian, ranks highest in national Internet development. Therefore, to further verify the robustness of the core findings, this paper tries to exclude these more developed Internet regions for robustness testing, and the test results are shown in Panel B of Table 6. The results show that DS still significantly increases the proportion of NFE and EP among rural laborers, further indicating the robustness of the core findings.

(5) Replacement of estimation method. The previous benchmark regression section used the panel Mprobit model, and this section is replaced with the panel Mlogit model for regression to verify the robustness of the core findings further. Moreover, the results are shown in Panel C of Table 6, which shows that the panel Mlogit model's regression results are more consistent with the benchmark regression results, indicating that the paper's core findings are robust and credible.

5. Further Analysis

5.1. Who Can Benefit More from Digital Upskilling?

The previous analysis shows that DS significantly improves the employment choices of the rural labor force. However, it is worth noting that this is only an average effect at the whole sample level and does not account for the heterogeneity of the impact of DS on rural laborers' employment choices. In order to obtain more detailed findings, this paper further

analyzes the heterogeneity of the impact of DS on rural laborers' employment choices in terms of the dimensions of regional economic development level, skill level, and gender differences.

5.1.1. Grouped by Different Economic Development Levels

Because there is a digital penetration gap and a digital capability gap in different regions [52], this paper divides provinces into three regions according to their GDP ranking: rich, middle, and poor. The regression results are shown in Table 7. DS can significantly increase the proportion of NFE in middle and poor regions. However, the effect on NFE is most significant in poor regions, while the effect on EP is most significant in wealthy regions. The main reason for this is that employment opportunities in poor regions are limited compared to those in wealthy regions. It is more difficult for individuals to obtain employment information, with less job matching. When rural laborers acquire digital skills, they can use the information dissemination function of the Internet to help them obtain more employment information. In rich regions, economic and digital development levels are higher. When rural laborers master digital skills, they can increase their probability of identifying entrepreneurial opportunities.

Table 7. The impact of DS on employment choices of rural labor force with different economic development levels.

Panel A: Dependent Variable Is NFE			
	Rich Regions	**Middle Regions**	**Poor Regions**
DS	0.0162	0.0301 ***	0.0346 ***
	(0.0141)	(0.0085)	(0.0065)
Control variables	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Observations	1880	3313	5486
Panel B: Dependent Variable Is EP			
DS	0.0233 *	0.0123 **	0.0231 ***
	(0.0122)	(0.0055)	(0.0028)
Control variables	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Observations	1880	3313	5486
Panel C: Dependent Variable Is AE			
DS	−0.0049 *	0.0003	0.0017 **
	(0.0028)	(0.0015)	(0.0007)
Control variables	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Observations	1880	3313	5486

Note: The control variables are consistent with Table 2; the standard errors in brackets are clustered at the provincial level; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5.1.2. Grouped by Different Skill Levels

Referring to the study of Acemoglu and Restrepo [29], the impact of the digital economy on the labor force with different skills varies considerably. Therefore, it is essential to explore the skill heterogeneity of DS on the employment choice of the rural labor force. Drawing on the studies of Autor et al. and Tian and Zhang [53,54], this paper defines the rural labor force with more than 15 years of education as a high-skilled labor force, those with education levels at high school and above and below college as the medium-skilled labor force, and those with education levels below high school as the low-skilled labor force. The results of the subsample estimation are shown in Table 8. The findings show that DS has the most significant impact on NFE and EP of low-skilled rural labor, consistent

with the findings of [51], implying that improving the DS of low-skilled rural labor is a prerequisite for inclusive growth in the digital era. Meanwhile, DS significantly reduced the proportion of the high-skilled rural labor force employed in agriculture, but the effects on medium-skilled and low-skilled agricultural employment were insignificant.

Table 8. The impact of DS on employment choices of the rural labor force with different skill.

Panel A: Dependent variable is NFE			
	High Skill	**Medium Skill**	**Low Skill**
DS	0.0270 ***	0.0348 ***	0.0291 ***
	(0.0099)	(0.0075)	(0.0061)
Control variables	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Observations	1218	1870	7591
Panel B: Dependent variable is EP			
DS	−0.0048	0.0134 **	0.0265 ***
	(0.0063)	(0.0061)	(0.0048)
Control variables	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Observations	1218	1870	7591
Panel C: Dependent variable is AE			
DS	−0.0056 **	0.0006	0.0007
	(0.0027)	(0.0032)	(0.0015)
Control variables	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Observations	1218	1870	7591

Note: The control variables are consistent with Table 2; the standard errors in brackets are clustered at the provincial level; ** $p < 0.05$, *** $p < 0.01$.

5.1.3. Heterogeneity in Gender

In a traditional "patriarchal society" in China, driven by the ideology of "men are in charge and women are in charge", there are apparent differences between rural male and female laborers regarding family roles and employment choices. Therefore, this paper investigates the heterogeneity of DS in rural laborers' NFE from a gender perspective, and the specific test results are shown in Table 9. The results show that DS has the most significant impact on female NFE and the most significant effect on male EP. The main reason for this is that, when compared with men, women face discrimination in the rural job market in terms of employment opportunities, income distribution, and financial access to services, and they have relatively fewer opportunities to go out because of their narrower scope of life and more homogeneous social relationships. However, with the recent boom in the digital economy, women can communicate with the outside world via the Internet and e-commerce platforms after acquiring digital skills, which can compensate for the "lack" of social capital and increase their employment channels, thereby increasing the proportion of NFE. Because of their higher risk tolerance, competitive awareness, human capital, and social capital, men have an advantage in entrepreneurial activities. Meanwhile, the rapid development of Internet finance in recent years has provided an opportunity to alleviate rural laborers' financing constraints. As a result, male rural laborers are more willing to start their businesses after acquiring digital skills.

Table 9. The impact of DS on employment choices of the rural labor force with different gender.

Variables	NFE		EP		AE	
	Female	Male	Female	Male	Female	Male
DS	0.0483 ***	0.0201 ***	0.0140 ***	0.0252 ***	−0.0015	0.0012
	(0.0050)	(0.0063)	(0.0036)	(0.0045)	(0.0013)	(0.0015)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4563	6116	4563	6116	4563	6116

Note: The control variables are consistent with Table 2; the standard errors in brackets are clustered at the provincial level; *** $p < 0.01$.

5.2. Mechanism Exploration

The acquisition of DS by rural laborers can significantly increase the diversity of their employment options, but how does DS influence rural laborers' employment choices? Based on the previous theoretical analysis, this paper contends that DS primarily influences rural labor's employment choices by alleviating information access constraints and financing constraints.

5.2.1. Information Channel Effect

Due to limited information, knowledge, and endowment, the rural labor force is in low-level employment. Therefore, information access ability is essential for rural laborers' participation in the digital economy. It benefits improving individual feasible ability, realizing diverse employment patterns, lowering employment search costs, and realizing efficient and accurate matching of human and job. Rural laborers with DS can use online platforms to transfer information, break down spatial and information barriers, and effectively alleviate the information constraints they face in the digital context. Because the Internet is primarily an online communication platform, it can remove barriers and gaps in the flow of information, bridge the digital inequality caused by the digital divide, and improve rural laborers' information acquisition and technology application abilities, allowing them to make better employment and entrepreneurial decisions. As a result, we used the question "The importance of the Internet, TV, newspaper, radio, and mobile SMS as information acquisition channels" from the China Household Tracking Survey (CFPS) questionnaire to examine the impact of DS on information acquisition ability, drawing on the study of Zhou and Fan [36].

Table 10 reports the results of the DS and information access mechanisms tests. The findings show that a rural workforce with DS can significantly increase the importance of the Internet, newspapers, radio, and mobile SMS as information access channels, with the Internet having the most significant impact. As the primary carrier of information technology, the Internet has the potential to improve the efficiency and breadth of information dissemination. Therefore, rural laborers with DS can improve their information acquisition ability by emphasizing the Internet as an information acquisition channel, with business skills having the most significant impact on alleviating information flow constraints, owing to the ability of rural laborers with business skills to use digital finance such as Internet platforms and mobile payment to quickly collect and filter information, thereby alleviating information flow constraints. The main reason for this is that rural laborers with business skills can use Internet platforms and mobile payment to collect and filter information quickly, thereby alleviating information constraints.

Table 10. Mechanism of action: effect of DS on information acquisition ability.

Variables	(1) TV	(2) Internet	(3) Newspaper	(4) Broadcast	(5) Mobile SMS
DS	−0.0023	0.3208 ***	0.0802 ***	0.0471 ***	0.1642 ***
	(0.0204)	(0.0165)	(0.0245)	(0.0142)	(0.0211)
Digital learning skills	−0.0182 *	0.1135 ***	0.1116 ***	0.0560 ***	0.0671 ***
	(0.0098)	(0.0109)	(0.0131)	(0.0103)	(0.0153)
Digital work skill	−0.0273 ***	0.1162 ***	0.0872 ***	0.0348 ***	0.0556 ***
	(0.0079)	(0.0091)	(0.0083)	(0.0069)	(0.0127)
Digital social skills	0.0112	0.1483 ***	0.0205 *	0.0050	0.0839 ***
	(0.0125)	(0.0120)	(0.0101)	(0.0101)	(0.0147)
Digital entertainment skills	0.0063	0.1555 ***	0.0214 **	0.0105	0.0484 ***
	(0.0122)	(0.0100)	(0.0099)	(0.0115)	(0.0108)
Digital business skills	−0.0201	0.2036 ***	0.0767 ***	0.0378 **	0.0930 ***
	(0.0164)	(0.0120)	(0.0164)	(0.0144)	(0.0140)
Control variables	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes
Observations	2212	2212	2212	2212	2212

Note: The control variables are consistent with Table 2; the standard errors in brackets are clustered at the provincial level; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5.2.2. Financing Constraint Effect

The existence of financing constraints is an important factor limiting the success of entrepreneurship, which harms the entrepreneurship of low-income people with entrepreneurial spirit but limited capital. In recent years, low-income groups excluded from traditional finance have been absorbed by inclusive digital finance derived from Internet technology due to its low cost and easy accessibility. When rural laborers master digital skills, they can effectively use inclusive digital finance to alleviate the problems of "difficult financing" and "expensive financing" they face. As a result, they equalize entrepreneurial opportunities. Therefore, in examining the impact of DS on financing constraints, this section employs a probit model to validate the impact of DS on rural laborers' borrowing behavior in terms of both formal credit (availability of bank loans) and informal credit (availability of private lending). Table 11 shows the regression results, which show that acquiring DS significantly increases the likelihood of rural laborers obtaining formal loans but has no effect on private lending. It suggests that the rural labor force's acquisition of DS ultimately improves their employment options, primarily by increasing their likelihood of obtaining loans from financial institutions. Furthermore, online business skills have the most significant impact on easing credit constraints for formal credit. The main reason for this is that rural laborers with online business skills can improve their efficiency in using digital financial technologies such as Internet platforms and mobile payments to collect information quickly and reduce financing and transaction costs, which can help make up for traditional finance's shortcomings, effectively solve the problems of "difficult" and "expensive" financing for rural laborers, improve financial accessibility, and remove formal credit's financing constraints.

Table 11. Mechanisms of action: effects of DS on financing constraints.

Variables	(1)	(2)	(3)	(4)
	Formal Credit (Bank Loans)		Informal Credit (Private Lending)	
DS	0.0608 ***		−0.0010	
	(0.0179)		(0.0102)	
Digital learning skills		0.0227 **		0.0048
		(0.0095)		(0.0064)
Digital work skill		0.0237 ***		−0.0012
		(0.0073)		(0.0056)
Digital social skills		0.0144		0.0022
		(0.0108)		(0.0091)
Digital entertainment skills		0.0214 ***		−0.0028
		(0.0071)		(0.0055)
Digital business skills		0.0504 ***		−0.0079
		(0.0114)		(0.0076)
Control variables	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Observations	10,679	10,679	10,679	10,679

Note: The control variables are consistent with Table 2; the standard errors in brackets are clustered at the provincial level; ** $p < 0.05$, *** $p < 0.01$.

6. Conclusions and Policy Implications and Limitations

The rapid development of the digital economy in recent years has resulted in many flexible employment workers and a variety of new employment forms, opening up more room for development to secure employment and entrepreneurship for urban and rural laborers. Furthermore, digital technology introduces new opportunities and challenges to China's labor market as an emerging technology. The main issue is how to effectively enable more laborers in less developed rural areas to fully benefit from the digital economy's employment dividends. Bridging the "utilization gap" of the rural labor force and improving rural labor force DS are the key points and concrete approaches to overcoming this problem. Based on this, this paper examines the impact of DS on rural labor force employment choices using CFPS data from 2014 to 2018. The findings show that, first, DS can significantly contribute to rural labor force NFE and EP, with each 1% increase in DS increasing rural labor force NFE and EP by 3.03% and 2.11%, respectively, indicating that DS is an essential factor influencing rural labor force employment choice. Second, the degree to which each DS affects rural laborer employment varies, with work skills having the most significant effect on promoting the NFE of rural laborers, and online business skills having the most significant effect on promoting EP. Third, the mechanism analysis demonstrates that DS improves the rural labor force's employment options by alleviating information access and financing constraints. Fourth, the heterogeneity analysis results show that DS promotes NFE among rural laborers, particularly among low-skilled rural laborers, and that males and rural laborers in less economically developed regions can benefit from EP. In contrast, females and rural laborers in economically developed regions can benefit more from NFE.

In the context of the digital economy, improving the DS of the rural labor force and promoting fuller and higher quality employment in the rural labor force is an effective way to "stabilize employment" and achieve shared prosperity. Rural laborers' low employment level is a "passive and helpless action" due to the lack of their resources. Building the personal "resilience" of rural laborers to participate more fully in the jobs created by the digital economy is undoubtedly critical to improving their employment options. The contribution of DS to the employment options of rural laborers demonstrates that DS can play an essential role in improving the employment options of rural laborers and promoting fuller and higher quality employment of rural laborers. Therefore, in order to give full play to the role of the "reservoir" of digital economy employment, this paper proposes the

following policy implications. First, a digital skills diffusion system for rural areas should be built, and efforts should be made to improve the viability of rural residents' digital skills and raise the awareness of the digital economy among rural laborers, making it a key focus of a series of policies to bridge the digital divide and achieve dividend sharing in the current and future periods. Second, emphasis should be placed on the development of digital skills, with a particular emphasis on the development of work skills, social skills, and online business skills in order to improve the viability of the rural labor force's ability to participate in employment and obtain well-paying jobs, so as to provide intrinsic motivation for the digital economy to play a greater role in "stabilizing employment" and promoting common prosperity. Third, we should adopt "precise support" measures for the disadvantaged labor force to improve digital technology adoption by the low-skilled rural labor force and rural women, narrow the "digital divide" in the use of digital technology by disadvantaged groups, and enable low-skilled rural labor force and rural women to truly learn the functions of digital technology such as information search, skill learning, and social communication, so that they can find suitable jobs.

This paper still has certain limitations. Our study discovered that digital skills significantly improve the employment choices of the rural labor force, but how much of a spillover effect does rural labor force digital skills have on the employment choices of the rural labor force in the village and surrounding villages? Will mastery of the digital skills of the rural labor force increase the income gap among rural households? These issues have not been resolved. We hope to address them in future studies as more data become available.

Author Contributions: Conceptualization, X.W.; methodology, Y.H.; software, Y.H.; validation, Y.Z; formal analysis, X.W.; investigation, J.F.; resources, J.F.; data curation, Y.H.; writing—original draft preparation, X.W.; writing—review and editing, Y.H; visualization, Y.Z.; supervision, J.F.; project administration, Y.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Social Science Foundation of China, grant number 19BGL256, and the National Natural Science Foundation of China, grant number 72264008.

Institutional Review Board Statement: Ethical review and approval were waived for this study as the study does not collect any personal data of the respondents, and respondents were informed that they could opt out any time from giving a response.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data will be provided upon request by the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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Using Genetic Programming to Identify Characteristics of Brazilian Regions in Relation to Rural Credit Allocation

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Abstract: Rural credit policies have a strong impact on food production and food security. The attribution of credit policies to agricultural production is one of the main problems preventing the guarantee of agricultural expansion. In this work, we conduct family typology analysis applied to a set of research data to characterize different regions. Through genetic programming, a model was developed using user-defined terms to identify the importance and priority of each criterion used for each region. Access to credit results in economic growth and provides greater income for family farmers, as observed by the results obtained in the model for the Sul region. The Nordeste region indicates that the cost criterion is relevant, and according to previous studies, the Nordeste region has the highest number of family farming households and is also the region with the lowest economic growth. An important aspect discovered by this research is that the allocation of rural credit is not ideal. Another important aspect of the research is the challenge of capturing the degree of diversity across different regions, and the typology is limited in its ability to accurately represent all variations. Therefore, it was possible to characterize how credit is distributed across the country and the main factors that can influence access to credit.

Keywords: rural credit; criteria analysis; family farming; genetic programming; machine learning

Citation: Araújo, A.V.; Mota, C.; Siraj, S. Using Genetic Programming to Identify Characteristics of Brazilian Regions in Relation to Rural Credit Allocation. *Agriculture* **2023**, *13*, 935. https://doi.org/10.3390/agriculture13050935

Academic Editors: Hung-Hao Chang, Pei-An Liao and Jiun-Hao Wang

Received: 1 April 2023
Revised: 14 April 2023
Accepted: 16 April 2023
Published: 24 April 2023

1. Introduction

Food insecurity is a global challenge, and the Central Rural Work Conference in 2021 pointed out that in order to ensure food security, attention should be paid to adjusting rural credit [1]. The allocation of credit to agricultural production is one of the main problems in ensuring agricultural expansion, since the credit is financed with lower interest rates than those adopted in the market [2]. Rural credit consists of loans provided by financial institutions to producers and rural cooperatives [3]. According to data from the Central Bank of Brazil [4], in 1999, the rural credit/agricultural GDP ratio was approximately 24%, and in 2018, it reached approximately 61%. The increase in rural credit and its importance to Brazilian agricultural policy become even more relevant when we consider studies that show the impact of positive rural credit on agricultural variables such as production value, agricultural products, agribusiness products, and total factor productivity [5,6].

Many studies from different parts of the world have shown significant economic and social elevation for the beneficiaries of rural credit programs [7]. In addition, many specialists believe that large farmers linked to global companies are key actors, based on both the size of their production and the potential for agricultural intensification. However, for other specialists, diversified systems of family agriculture allow for greater potential for development. Other experts analyze the impact of public policies on the well-being and economic improvement of rural areas around the world, concluding that rural credit policies represent an essential factor in the development of agriculture [8,9]. Although some studies have addressed rural credit, no study has sought to understand how rural credit is allocated to farmers, and no specific technique or methodology has been used to properly assess rural credit for the actors involved.

The difficulty in finding studies related to the conception of rural credit is due to the complexity of the rural credit system. For example, the government of Brazil has a complex set of funding sources and rural credit programs and offers a range of credit lines targeted at producers with different income levels and property sizes. However, flaws in the current design lead to substantially reduced access and distribution of rural credit. This diminishes the benefits of the policy and threatens the country's ability to balance its agricultural productivity with environmental preservation [3].

During the 2017 agricultural year, the Brazilian rural credit system offered 18 sources of financing. Important differences existed among these funding sources in terms of beneficiary qualification criteria and funding conditions. This generated a complex system and made it difficult for creditors and debtors to define the best credit option in each case. The complex set of rules for the different credit lines was not only excessively complicated for the agents operating the system but also generated distortions in the allocation of resources [10].

It is argued that the current structure favors the three public banks: (1) Banco do Brasil, the main creditor in the sul, sudeste, and centro-oeste revisions; (2) Banco do Nordeste, the main creditor in the nordeste region; and (3) Banco da Amazônia, the main creditor in the norte region. Considering the BRL 218 billion made available during the 2017–2018 harvest, which represents approximately 7% of the balance of credit operations in the entire financial system, rural credit is restricted to a small portion of rural establishments in Brazil. According to the Brazilian Institute of Geography and Statistics (IBGE) [11] only 15.5% of rural establishments had access to the rural credit system. Among those who did not obtain it, 42.8% stated reasons that did not prevent them from taking out rural credit. Such values correspond to the existing paradigm at specialized rural credit institutions [12] and, consequently, to the hypothesis of rural credit rationing in the country [13,14]. Banco do Brasil, the public bank, provided 47% of all loans in the 2017 fiscal year. Itaú and Bradesco, two of the most important private banks in Brazil, together with Banco do Brasil, provided about 60% of all loans in the same period. Credit cooperatives were responsible for another 15% of rural credit in 2017 [10].

In this respect, guaranteeing access to rural credit for all farmers, and not just for a minority, is considered a vital requirement for sustainable economic growth and for improving the quality of life in less developed countries. In order to understand the rural credit allocation process, we used family typology analysis applied to a research dataset to characterize different regions. Previous studies used several approaches to determine rural credit but did not take into account the complexity of heterogeneous family farming systems. There is no work in the literature that characterizes how rural credit, an important public policy that has been adopted by several countries, is conceived. Therefore, it was necessary to investigate and characterize the allocation of rural credit to different Brazilian regions using an artificial intelligence technique. The technique used in this study was designed using user-defined terms to identify the importance and priority of each criterion used for each region. Thus, farmers who are interested in accessing rural credit may have a better decision-making capacity in relation to the most important criteria in a given region.

This paper is organized as follows: Section 2 presents the bibliographic review, and Section 3 describes the genetic programing. In Section 4, we discuss the method, and in Section 5, we discuss the results. Finally, we provide the conclusion in Section 6.

2. Bibliographic Review

The period of 1995 to 2022 was selected for this systematic review, because the National Program to Strengthen Family Farming (PRONAF) was created in 1995. PRONAF was introduced to support family farmers because there was an increase in farmer indebtedness and non-payment [15].

For the systematic review, first, the criteria for inclusion were defined, followed by the systematic implementation of defined search strings across the Web of Science, Scopus, and SciELO databases. To achieve quality and ensure relevance to the topic, only articles

that were published in respected international peer-reviewed journals were shortlisted. All other publications, including conference articles, post-graduation theses, and editorial notes, were excluded from this review. This approach allowed for a description of the techniques, methodologies, applied tools, and possible trends in the bibliography, as well as the gaps in research on rural credit. Peer-reviewed articles were included in the analysis based on the criteria listed in Table 1.

Table 1. Inclusion criteria for the systematic review.

Category	Inclusion Details
Language	Non-English studies have been excluded
Publication date	Any studies prior to 1995 have been excluded
Peer-reviewed	Only peer-reviewed articles have been included
Geography	Only studies related to rural credit around the world
Primary data	Only the studies presenting primary data
Subjects	Only those studies that relate to family farming
Treatment	The studies must be related to rural credit, or to one of its practices or pseudonyms, as a financing policy
Rural credit aspect	Studies must be related to one or more aspects of Rural Credit: • Criteria (quantity) • Methodology • Tools • Distribution

The next step was to define the keywords (search strings) to be used in the first filter to select the articles. The words defined in advance were "rural credit" and "family farming", "rural credit distribution", "rural credit measurement", and "indicators of rural credit" as terms on one axis of the theoretical background. The keywords connected to rural credit and family farming were combined to form the other axis of the research. Then, the keywords were constructed, as shown in Table 2.

Table 2. Keywords.

Keywords	TOPIC—Search Strings in the Title and Summary of the Articles
P1	Topic = ("Rural Credit") AND Topic = ("Family Farming")
P2	Topic = ("Rural credit distribution") AND Topic = ("Family Farming")
P3	Topic = ("Rural credit measurement") AND Topic = ("Family Farming")
P4	Topic = ("Indicators for rural credit") AND Topic = ("Family Farming")
P5	Topic = ("Model used in rural credit") AND Topic = ("Family Farming")
P6	Topic = ("Distribution of public resources in agriculture") AND Topic P1
P7	Topic = ("Agriculture performance") AND Topic P1
P8	Topic = ("Tools used in agriculture") AND Topic P1
P9	Topic = ("Criteria for public resources") AND Topic P1
P10	Topic = ("Methodology used in sustainable agriculture") AND Topic P1

Then, the articles that were considered to be aligned with the theme of this research were analyzed using the Journal Citation Reports (JCR) of their respective publishers. The objective was to verify whether they possessed a JCR impact factor (IF) score different from zero. As a quality standard, only journals with a JCR IF greater than zero were included in this research.

Selection of the Theoretical Framework

Using the inclusion criteria for the systematic review and the defined keywords, the search of the database yielded 2699 results. The summaries of those 2699 articles were then analyzed to check whether their themes were aligned with the research. After this initial analysis, 2597 references were excluded for not being aligned with this research or for being duplicates. Then, the 102 remaining articles were analyzed using the JCR criterion. It was observed that 49 did not meet the requirements, meaning that the JCR indicator was zero. Hence, the remaining 53 articles were aligned with regard to the title and abstract and met

the JCR requirement established by the researcher. Those articles were then read in full in order to evaluate whether they would contribute valuable information to this study. In this process, three articles were excluded, resulting in 50 articles, as shown in Figure 1.

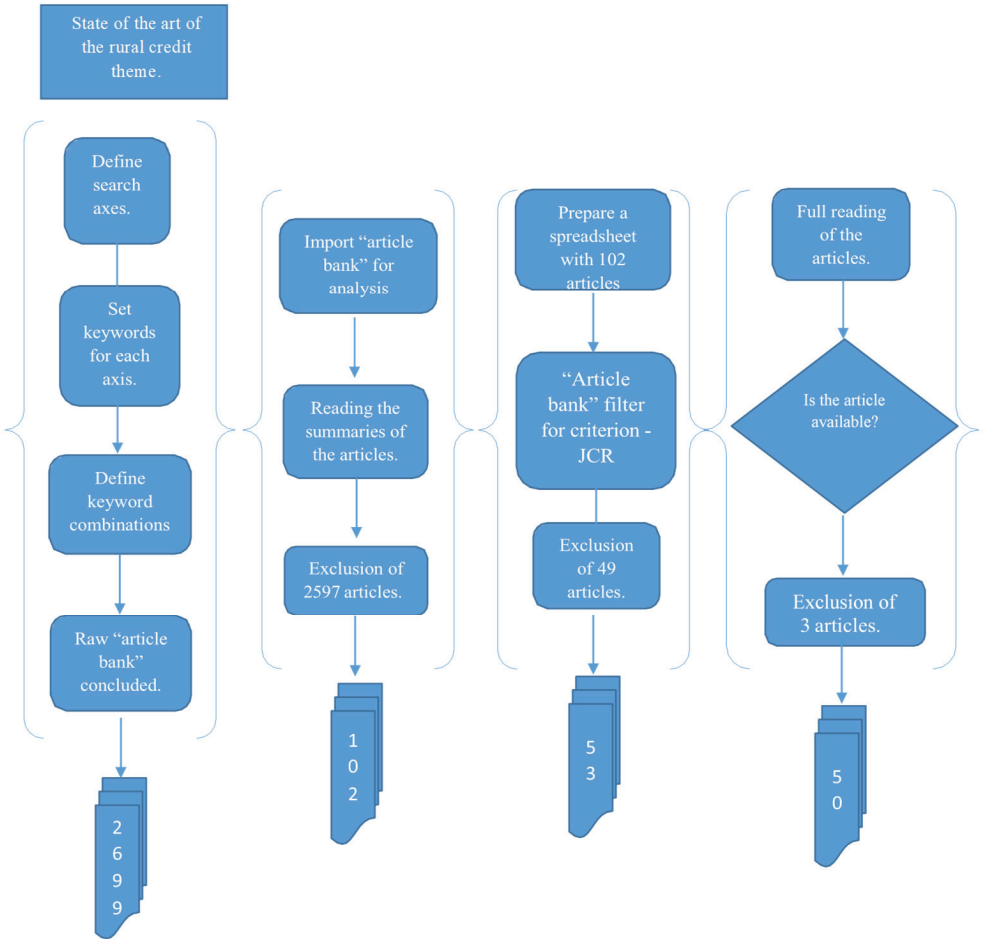

Figure 1. Flowchart illustrating the systematic review process.

Figure 2 shows the systematic process for the visualization of techniques and criteria from the identification of 50 papers deemed eligible for full analysis. For this research, we divided the articles into five techniques that were used in their respective work: statistical, computational, multicriteria, exploratory review, and other. The aim was to find a technique that could apply to the work, considering its limitations.

A total of 72% of articles reported a quantitative approach, among which 16% used statistical techniques to solve the problems [16–23]. Computational techniques were used in 28% [8,24–37]; multicriteria techniques were used in 22% [38–48]; literature review, a qualitative approach, was used in 28% [49–62]; and other types were used in 6% [63–65], Table 3.

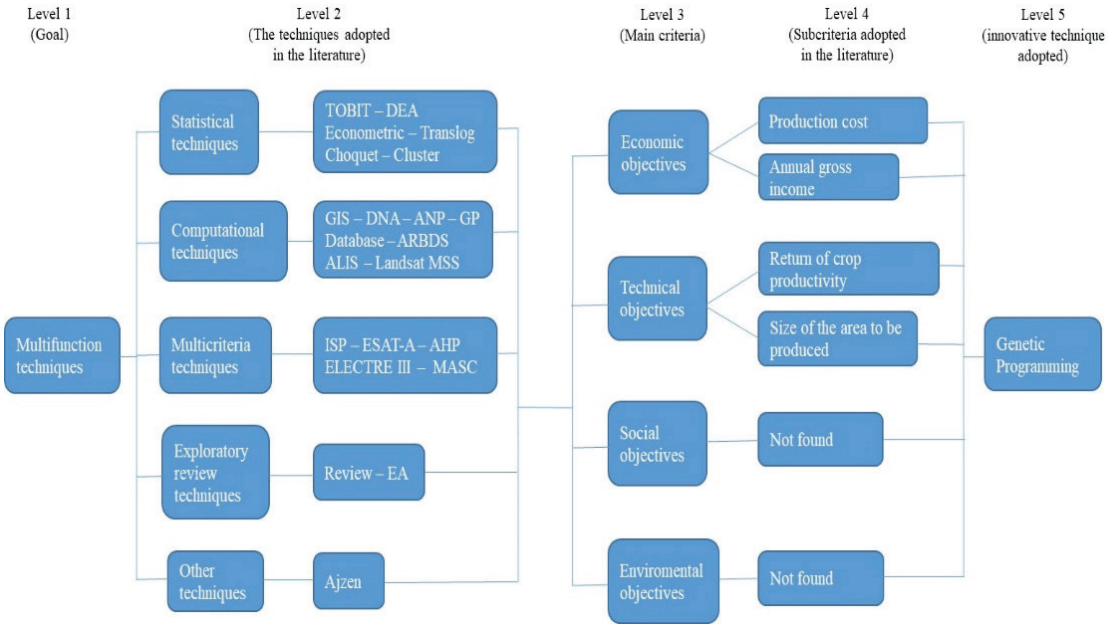

Figure 2. Flowchart illustrating the systematic process.

Table 3. Percentage of technical approaches.

Total Percentage of Techniques Adopted in the Literature	
Statistical techniques	16%
Computational techniques	28%
Multicriteria techniques	22%
Literature review	28%
Other types	6%

3. Genetic Programming

Genetic programming has attracted attention for solving credit problems, both academically and empirically, and is mainly implemented for problems with less information. For genetic programming, it fits as a machine learning method, but unlike with other learning methods, the answer is already a readable and interpretable model in the form of a program. When we are able to define the language in which the program will be written, the obtained program will be explicitly interpretable and will not require an additional step to understand the decision-making process. For example, in [62], the authors performed an analysis of credit scoring models for public banks using two evaluation criteria: the average correct classification (ACC) rate and estimated misclassification cost (EMC). The results revealed that GP had a higher ACC and lower EMC compared to other techniques [62]. Another example supports the recommendation to use the "genetic programming in two stages" (2SGP) technique to deal with credit scoring problems, incorporating IF–THEN rules and more complex discriminating functions. Based on the numeric results, the conclusion is that 2SGP can offer better precision than other models, and this improvement can result in significant savings [63].

Other studies related to credit supply describe a relationship to economic growth. For example, in [66], the authors used the coherence test to answer the following question: (i) does the offer of bank credit lead to economic growth? Another study [67] examined

the causal link of sectoral economic credit growth in Australia using a coherence test. The results for both studies determined according to dynamic time and frequency analysis reveal that economic growth generates credit for the agricultural sector in the long term.

4. Method

A structured questionnaire-based survey was conducted using the IBGE data collection platform to collect pooled information from 264,359 agricultural households. Through multivariate analysis, a typology of family farming types was developed based on fourteen area ranges, totaling seventy groups of agricultural households. Subsequently, discussions of these seventy groups were conducted using criteria developed through the survey. The purpose of the discussions was to validate the typology of family farming and to explore and characterize the rural credit granted to agricultural households. In addition, the genetic programming technique was introduced through the Bitbucket website (https://bitbucket.org/ciml (accessed on 1 June 2022)), which is public and allows for free collaboration. The implementation is in C++, and all tests were performed on the Debian/Ubuntu Linux operating system to obtain conclusions that could help in decision making.

4.1. Study Area

For this research, the study area was divided into five regions: Norte, Nordeste, Sudeste, Sul, and Centro-Oeste (Figure 3).

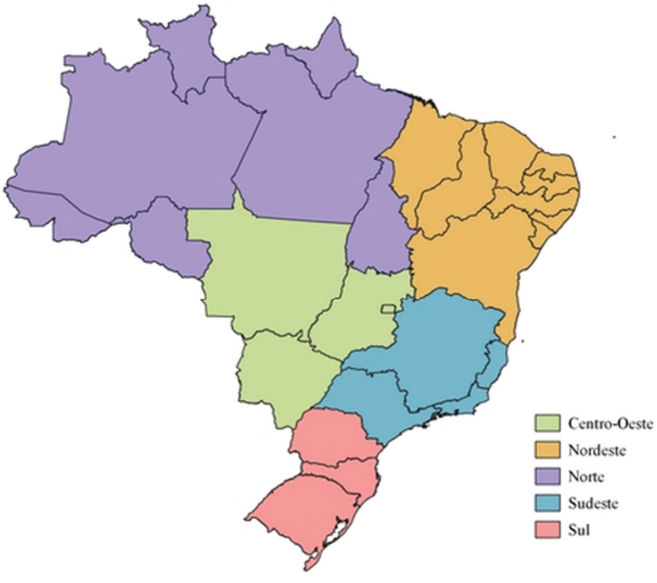

Figure 3. Map of Brazil showing the study areas.

4.2. Survey

The dataset covers the period from June 2007 to July 2017 [10]. To evaluate the criteria, first, a document is used, which is the gateway to public policies [11,68]. Considering the legal and regulatory framework in force on 30 September 2017, the information available in the 2017 Agricultural Census, the definitions used in the 2006 Agricultural Census, and the opinions of the technical management of the Agricultural Census (GTA) of IBGE, several algorithms were proposed [69]. When their credit applications were processed, all farmers were evaluated according to the following criteria:

- The total gross income of the agricultural household does not exceed BRL 500,000.
- The area of the property does not exceed four fiscal modules, a unit of measurement in hectares, whose value for each municipality is determined by the National Institute of Colonization and Agrarian Reform (INCRA).
- Farmers predominantly use their own family's labor for the activities of the establishment or enterprise.
- Farmers have a PRONAF Aptitude Declaration (DAP).

In addition to these classification criteria, the proposed model was generated by four independent criteria—production cost, annual gross income, return to crop productivity, and size of the area to be produced—and a dependent criterion: number of establishments that received rural credit (Table 4).

Table 4. List of variables of the model.

Variables	Code	Description
x_1	Territorial Region	Norte, Nordeste, Sudeste, Sul, Centro-Oeste
x_2	Typology	Family farming
x_3	Area range	Fourteen groups of categorized areas
x_4	Productivity	Production value of agricultural establishments (per thousand Reais (BRL))
x_5	Cost	Value of expenses incurred by agricultural establishments (per thousand Reais (BRL))
x_6	Income	Value of income or income obtained by agricultural establishments (per thousand Reais (BRL))
Y	Approved quantity	Quantity of establishments that received rural credit

With this set of criteria, genetic programming was used to characterize rural credit. For this work, two scenarios were developed in an attempt to find a function that would explain it analytically:

- Scenario 01, using the dataset separately for each region.
- Scenario 02, a generalist function using the entire dataset without separating by region.

Some authors use absolute error for fitness functions [64,70], while others use linear combinations of the mean square error and mean classification error [71]. In this paper, we preferred the latter approach. The fitness function, F, for evolution was calculated as follows:

$$F(ep) = \sum_{i=1}^{n} \frac{|a_i - e_i|}{n}$$

where F is the fitness function, ep is the evolved program, a_i is the actual observation, e_i is the expected (predicted) observation, and n is the sample size.

4.3. Typology Construction

The typological approach has previously been used in studies to characterize farming families [72,73]. The advantage of organization and the use of aggregated data is that the data are more stable, and this approach is widely used to build typologies of farmers [74,75]. Therefore, the aggregated data for this research were organized and used for different categories of agricultural areas corresponding to each region (Table 5).

Table 5. Sample size determination.

	Norte	Nordeste	Sudeste	Sul	Centro-Oeste
Total population of farmers	10,764	73,612	56,229	112,830	10,924
Sample size (0–0.1 ha)	38	406	89	38	4
Sample size (0.2–0.5 ha)	49	364	72	27	1
Sample size (0.5–1 ha)	68	1455	197	63	1
Sample size (1–2 ha)	144	4069	384	200	7
Sample size (2–3 ha)	148	8641	1622	585	34
Sample size (3–4 ha)	142	6501	2584	1296	65
Sample size (4–5 ha)	148	5506	2837	1993	59
Sample size (5–10 ha)	486	3915	3136	2809	253
Sample size (10–20 ha)	1023	11,837	9951	17,758	964
Sample size (20–50 ha)	3204	11,460	13,060	32,152	1844
Sample size (50–100 ha)	2621	12,536	14,788	42,114	3110
Sample size (100–200 ha)	2072	4783	5994	13,464	2777
Sample size (200–500 ha)	615	1811	1403	326	1378
Sample size (500–1000 ha)	6	328	112	5	427

4.4. Typology Validation

Evaluating aggregate data involves analyzing and interpreting data that have been combined. The steps used in the research to evaluate the aggregated data, according to [76], are as follows:

- Understand the purpose and context of the data. For this research, we did not want to use the machine learning technique for prediction but rather to characterize rural credit.
- Check the data quality. We used a reliable Brazilian census [11], which is prepared by a trustworthy technical team that carries out mapping in different areas. The aggregated data were certified as complete by eliminating missing data.
- Compare the data. The literature was compared with data obtained from the census to identify similarities and differences.
- Draw a conclusion. Based on the analysis, conclusions and recommendations were made. It is important to be cautious when interpreting data and consider the limitations.

Therefore, evaluating aggregated data requires a systematic approach that involves understanding the purpose and context of the data, checking the data quality, analyzing the data, comparing the data, drawing conclusions, and communicating the results. For this research, the use of aggregate data was justified by the objective of the work, which was to characterize farmers from different regions regarding their willingness to receive rural credit. The interest of the research was to group agricultural households according to total area and not to infer the information of each farmer.

5. Results

5.1. First Scenario

Following the methods described above, five regions were characterized using the equations generated by the genetic programming technique based on symbolic regression. The five regions presented the output of the model (evolved program). The characterization of regions was carried out according to the variables used in the model (Table 6).

To verify the robustness in terms of whether the characterization generated by the model resembled reality, the model was validated through discussion based on the literature [77]. Equations for each region were developed. From these equations, we identified the variables that allowed for a qualitative comparison (no, low, moderate, or high influence) for the approved number of agricultural establishments in relation to rural credit among regions (Table 7).

Table 6. Characterization of regions based on their variables.

Characterization of Regions Based on Their Variables	Territorial Region	Evolved Program
$x_3 = area$ $x_6 = income$	Norte	3.21507
$x_3 = area$ $x_5 = cost$	Nordeste	44.57690
$x_3 = area$ $x_4 = productivity$ $x_6 = income$	Sudeste	52.21970
$x_5 = cost$ $x_6 = income$	Sul	29.76710
$x_3 = area$ $x_4 = productivity$ $x_5 = cost$	Centro-Oeste	0.92433

Table 7. Characterization of the type of region identified.

Territorial Region	Equation	Area	Productivity	Cost	Income
Norte	$ep = \frac{3^{x_3}}{5^{x_3}} x_6$	Moderate influence	No influence	No influence	High influence
Nordeste	$ep = \frac{(x_5)}{(81+(x_3-4))+\left(\frac{1}{x_3}+2\right)^{(x_3-5)}}$	Moderate influence	No influence	High influence	No influence
Sudeste	$ep = \begin{cases} \frac{3^{x_3}}{1027} x_3 \leq 10 \\ \frac{x_6^2}{5x_4} > 10 \end{cases}$	High influence	No influence	High influence	High influence
Sul	$ep = \frac{x_6 - x_5}{93}$	No influence	No influence	Low influence	High influence
Centro-Oeste	$ep = \begin{cases} \frac{x_4}{x_5} x_3 > 5 \\ x_4 x_3 \leq 5 \end{cases}$	High influence	High influence	Low influence	No influence

Norte: According to the GP model, the higher the income of farming families, the greater the chance their farms will obtain approved rural credit. Nordeste: According to the GP model, the higher the production cost for farming families, the greater the chance their farms will obtain approved rural credit. This implies that the Nordeste region has high production costs and needs access to rural credit to produce. This reflects reality, as this region has low agricultural production compared to other regions [77]. Sudeste: The GP model allows for inequality, with the characterization of rural credit being represented by the variables area, productivity, and income. According to the model, for farms with an area greater than 10 hectares, income positively influences the allocation of rural credit. When the area is less than or equal to 10 hectares, the function is totally dependent on the area. Sul: According to the GP model, the greater the difference between income and cost for agricultural families, the greater the chance their farms will obtain approved rural credit. Centro-Oeste: The GP model allowed for an inequality, with the characterization of rural credit being represented by the variables area, productivity, and cost. According to the model, for establishments with an area greater than 5 hectares, the ratio of productivity and area has a positive influence on the allocation of rural credit. The cost for this area range has a negative influence. When the area is less than or equal to 5 hectares, the function is represented by the variables area and productivity, and the greater this ratio, the greater the chances that establishments will have approved credit.

5.2. Second Scenario

The GP model allowed for an inequality, with the characterization of rural credit being represented by the variables area, productivity, cost, and income. According to the model, for establishments with an area equal to or greater than 20 hectares, the productivity and area ratio positively influences the allocation of rural credit. Cost and income for this area range have a negative influence. When the area is in the range of 10 to 20 hectares, the function is represented by the variables area, productivity, and income, and the greater the positive relationship between the area and productivity, the greater the chances the establishments will obtain approved rural credit. When the area is less than or equal to 10 hectares, cost has a positive influence (Table 8).

Table 8. Characterization of Brazil.

Territory	Equation	Total Area Groups	Evolved Program	Variables
Brazil	$ep = \frac{64(x_5 - x_3^5 - 3130)}{9409}$	$x_3 \leq 10$	646.33000	$x_3 = area$ $x_5 = cost$
	$ep = \frac{2x_3 + x_4 - x_6}{85}$	$10 < x_3 < 20$		$x_3 = area$ $x_4 = productivity$ $x_6 = income$
	$ep = \frac{(x_3)^3 + (x_3 \times x_4) - x_6}{(x_5)^2}$	$x_3 \geq 20$		$x_3 = area$ $x_4 = productivity$ $x_5 = cost$ $x_6 = income$

Different regions have different degrees of need when making decisions based on the analyzed variables. Therefore, according to the characterization of the territory in relation to the allocation of rural credit, this research demonstrates that using a single rule to describe Brazil would not be ideal.

5.3. Discussion of the Findings

The advent of models generated via machine learning has impacted the world in different ways, with a presence in practically all areas of knowledge [78]. In some areas, models are applied directly, while in others, they function as a decision-making tool. However, in order to make a decision, it is desirable to understand how it was taken, which is where several learning models fail. A current example is the use of deep learning to generate artificial neural networks: although they are highly accurate, there is a trade-off between accuracy and complexity, making it difficult to extract information about how they work.

The need to explain these models leads to them being restricted or to the use of auxiliary tools capable of generating a more familiar representation of the model. Local Interpretable Model-Agnostic Explanations (LIME) is a tool that can identify an interpretable model that is locally true to the original [78]. Developed by researchers at the University of Washington to achieve greater transparency in terms of what happens inside the model, LIME has become very popular in the community for explaining AI models. When it comes to developing a highly accurate model, explainability is more difficult to achieve due to increasing complexity. For problems with higher dimensions, the lack of explainability is even more evident. Interpretability is an advantage for symbolic regression, as developed by the GP model; in this research, productivity is seen as contributing to the description of "approved rural credit", while the high cost of production is evidenced as "without approval".

For example, studies indicate [66,67] that access to credit provides economic growth, improving agricultural productivity and providing higher incomes for family farmers, as observed by the result of the model for the Sul region. As another example, for the Nordeste region, the cost criterion is relevant, and according to studies [62,77], the Nordeste region has the highest number of family farm households and is also the region with the lowest economic growth. Therefore, it lacks technological development, allowing for higher production costs. Therefore, the decision-making process can be based on a non-black-box model with a clear understanding of how the decision was made (Figure 4).

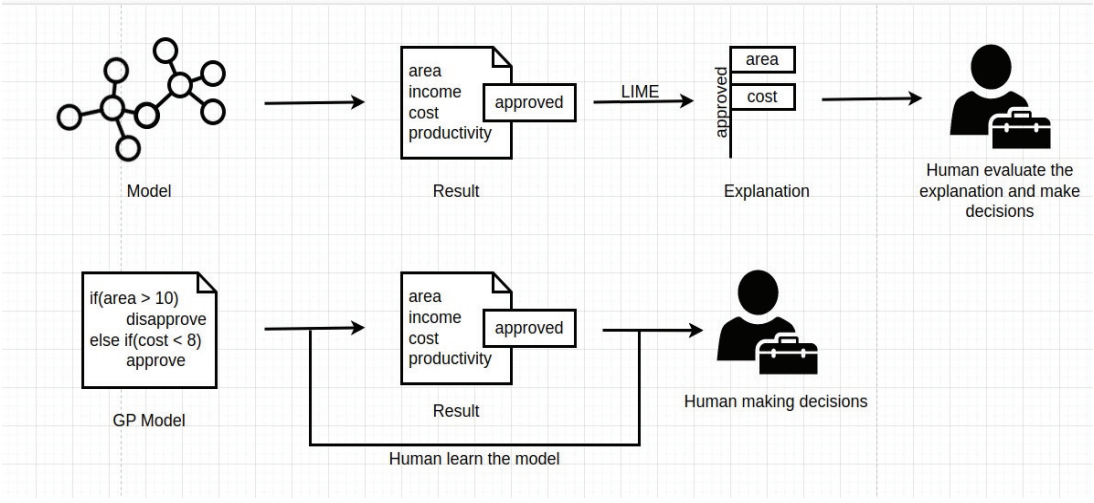

Figure 4. A model providing an answer based on data. LIME builds possible explanations according to why that answer was given.

6. Conclusions

The improvement of state-sponsored agricultural policies plays a decisive role in maintaining the distribution of rural credit. Groups of family farmers seek to introduce credit instruments to help them become more competitive on the agricultural market. However, the budget constraints of rural credit make it difficult to purchase items such as agricultural inputs. An important aspect discovered by this research is that the allocation of rural credit is not ideal. Another important aspect of this research is the challenge of capturing the degree of diversity in different regions, and the typology is limited in its ability to accurately represent all variations. Given the large territorial extent of Brazil and its characteristic heterogeneity in terms of demographic, economic, and cultural diversity, it is a challenge to develop a rural credit model to be applied universally. However, it is possible to characterize how credit is distributed across the country and the main factors that can influence access to credit; therefore, this is strong and innovative research, since public policies for rural credit are worldwide, and many countries that are in the same condition as Brazil have this problem. Therefore, using the machine learning technique could provide a better understanding of the regions according to the needs of agricultural households. In addition, GP models can help in implementing policies for smallholder support services. The technique used in this study was designed to generate a symbolic response using user-defined terms and identify the importance and priority of each criterion used for each region. Thus, those who are interested in rural credit may have better decision-making ability in relation to the most important criteria in a given territorial group and region.

Author Contributions: Conceptualization, A.V.A. and C.M.; Methodology, A.V.A. and S.S.; Validation, A.V.A., C.M. and S.S.; Formal analysis, C.M.; Investigation, A.V.A.; Resources, A.V.A.; Writing–original draft, A.V.A.; Writing–review & editing, A.V.A.; Supervision, C.M. and S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: https://sidra.ibge.gov.br/pesquisa/censo-agropecuario/censo-agropecuario-2017/resultados-definitivos (accessed on 31 March 2023).

Acknowledgments: Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and CNPq.

Conflicts of Interest: The authors declare no conflict of interest.

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Article

The Influence of Good Agricultural Practice (GAP) on the Productivity and Well-Being of Malaysian Sustainable Palm Oil (MSPO)-Certified Independent Smallholders in Malaysia

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Abstract: Good agricultural practice (GAP) helps increase productivity by producing fresh fruit bunches (FFBs), and selling FFBs will increase Independent Smallholders' (ISH) income. However, although GAP promotes increased productivity, the effectiveness of GAP in delivering the well-being of the ISH in oil palm production areas remains to be determined. To that end, this study (i) measures the smallholder's well-being index, (ii) compares the well-being index by states in Malaysia, and (iii) maps the relationship between GAP implementation, productivity, and well-being. The study selected respondents using purposive sampling (PS). PS identifies and selects individuals with Malaysian Sustainable Palm Oil (MSPO) certification and knowledge and experience of GAP. As a result, the research interviewed 564 ISHs with MSPO certification from 162 Sustainable Palm Oil Clusters (SPOC). The study used Principal Components Analysis (PCA) and the Structural Equation Model (SEM) framework to achieve the objectives. The study found that the average ISH well-being index was 0.62, and ISHs in Sabah had the highest well-being, with 0.73 compared to other states. The study also found that GAP influences productivity and is positively and significantly related to well-being. Therefore, it indicates to ISHs and the government the importance of GAP implementation to increase ISHs' productivity and well-being.

Keywords: good agricultural practice; independent smallholder; Malaysian Sustainable Palm Oil; palm oil; well-being

Citation: Mohd Suib, N.A.b.; Salleh, N.H.M.; Shukor, M.S.; Chamhuri, N.; Shahimi, S.; Salleh, K.M.; Hashim, K. The Influence of Good Agricultural Practice (GAP) on the Productivity and Well-Being of Malaysian Sustainable Palm Oil (MSPO)-Certified Independent Smallholders in Malaysia. *Agriculture* **2023**, *13*, 990. https://doi.org/10.3390/agriculture13050990

Academic Editors: Hung-Hao Chang, Pei-An Liao and Jiun-Hao Wang

Received: 31 March 2023
Revised: 21 April 2023
Accepted: 22 April 2023
Published: 29 April 2023

1. Introduction

The scientific name of palm oil from West African woods is Elaeis Guineesis. The name "Guineesis" denotes that the original specimen originated in Guinea, a country in West Africa. However, the world's oil palm industry is seen to be more developed in Southeast Asian regions such as Malaysia. The history of the oil palm industry in Malaysia began in 1848, when four seedlings of this plant were brought to and planted in the Bogor Botanical Garden, Indonesia. The first plant was used on the roadside as an ornamental plant in Deli, Sumatra, because it has a beautiful clump. In 1911, it was brought to Malaysia in Rantau Panjang, Kuala Selangor, with the same purpose. However, its economic potential was first realized by the government in the 1960s through the establishment of the Federal Land Development Authority (FELDA) to eradicate the people's poverty by cultivating oil palm and rubber plants. In the late 1970s and 1980s, Malaysia's oil palm industry was developed very widely and made oil palm the country's main commodity crop.

Now, Malaysia is the world's second-largest oil palm producer after Indonesia, followed by Thailand, Colombia, and Nigeria (Figure 1). Malaysia recorded production

between 18 and 20 million tons per year, with a growth rate of around 2% in 2020–2022. Meanwhile, Indonesia's production has increased yearly, reaching 46 million tons in 2022. Indonesia's production growth rate is around 4% for the same period. The production growth rate in other countries also increased, although on a small scale. According to [1], the increase in palm oil production is due to the rapid demand for vegetable oil, widely used in foods, industrial applications, and bioenergy.

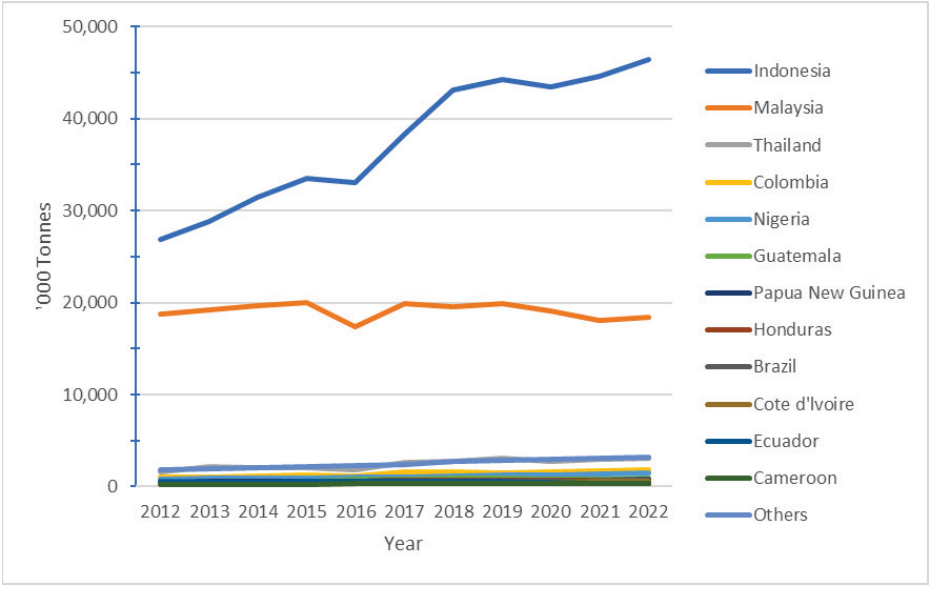

Figure 1. World's major producers of palm oil, 2012–2022. Source: Adapted from [2].

However, the development of the palm oil industry in this region has led to severe environmental issues. Because of the haze issue affecting most countries in Southeast Asia in the late 1990s, the world's oil palm industry has often received strong criticism from non-governmental organisations and environmental activists [3]. Among the other criticisms, the issue of afforestation on a large scale for the opening of oil palm plantations, which affects the environment and land ownership, is also often debated worldwide. The change in land use from forest areas to oil palm cultivation destroys biodiversity, causes soil erosion and the existence of crop residues, and reduces water and air quality [4–8]. In addition, palm oil-producing countries practice cutting and burning for land clearing and drainage in peatland areas [9]. This practice harms the ecological system and causes forest burning and carbon dioxide emissions, ultimately contributing to climate change [10,11]. As a result, some countries have launched anti-palm oil campaigns, such as the European Union, which restricts the import of palm oil to stop deforestation in Indonesia and Malaysia [12,13].

Another issue involving palm oil is global consumer awareness of the importance of sustainability for every product produced. For example, Ref. [14] found that consumers in the United Kingdom (UK) view products containing palm oil as having a negative impact on the environment and sustainable development in the production area. A similar consumer perception of the presence of palm oil in foodstuffs in Spain and Peru was found in [15]. Peruvian consumers believe that the selection of palm oil products is one of the worst compared to other vegetable oils when considering the environmental impact. Meanwhile, Spanish consumers consider the content of palm oil terrible for their health and the environment. This increase in consumer awareness is supported by [14–18]'s analysis of consumer perceptions of products containing palm oil. Although they know the benefits of palm oil and still buy products containing palm oil, they believe it has harmed

the environment and society [14]. The world's palm oil industry continues to face this pressure when the primary users of palm oil stipulate that they only use palm oil made by certified producers.

The Malaysian government, through the Malaysian Palm Oil Certification Council (MPOCC), has introduced the Malaysian Sustainable Palm Oil (MSPO) certification to counter these negative perceptions and address consumer issues that arise. MSPO is a national scheme introduced to Malaysia's smallholders and oil palm milling industry. MSPO has seven principles, one of which is good practice, which includes good agricultural practice (GAP). According to [19], GAP is a set of agricultural management practices used at the farm and post-production levels for producing safe and quality artificial products and food that are sensitive to economic, social, and environmental considerations. Meanwhile, the Department of Agriculture (as cited in [20]) stated that GAP is a resource management system for sustainable agricultural production, increasing productivity and producing safe and quality food. However, the use of the term GAP differs according to the smallholder's needs, the type of agriculture, and the producing country.

For example, in Ethiopia, GAP implementation for soybean farming consists of seven techniques: land selection and preparation, variety and seed selection, inoculation, applying fertiliser, planting, field management, and harvesting. Smallholders implement this GAP to produce good output and minimise costs. It also increase smallholders' productivity, with output as high as 3500–4000 kg/ha (sole crop) [21]. Therefore, soybean GAP is needed in Ethiopia to improve productivity and product quality while also saving costs. Singapore applies GAP in the production of vegetables. Six key areas are used as guidelines for small vegetable farmers: farm location, farm structure, farm environment, farm maintenance, farming practices, and farm management. These practices are formulated based on the Hazard Analysis of Critical Control Points (HACCP) [22]. Thus, the need for vegetable GAP in Singapore emphasises environmental care.

As for palm oil GAP in Malaysia, it comprises nine management techniques: land preparation, soil conservation, weed control, fertiliser application, pruning, pest control, disease control, harvesting, and record keeping. The implementation of GAP by palm oil smallholders is divided into three levels of compliance: compulsory practice, mandatory practice, and encouraged practice. According to [23], palm oil GAP in Malaysia is the basis for increasing productivity and is a requirement for sustainability certification. Therefore, it is necessary to include GAP in MSPO criteria. The purpose for GAP for palm oil in Malaysia is to increase productivity and protect the environment. Although the formation of GAP differs according to the needs of smallholders, the type of agriculture, and the producing country, the goal of GAP is broad and continuous, as it considers the interests of the whole society [24].

Moreover, GAP compliance by smallholders through sustainability certification is more effectively encouraged. Although the impact of GAP is diverse, for this study, only the impact of GAP on the productivity of smallholders is discussed. Regarding productivity effectiveness, Ref. [25] argue that certification schemes such as that of the Roundtable on Sustainable Palm Oil (RSPO) actively promote GAP compliance by palm oil smallholders, which can guarantee increased productivity. A study by [26] in Jambi, Indonesia, found that fresh fruit bunch (FFB) weight increased to 21 kg after the first six months of GAP implementation. The authors of [27,28] also support applying GAP, which is part of the principles and criteria of the RSPO, and found that it achieves high yields. A study by [28] in Kotawaringin Barat District, Indonesia, found that GAP produces significantly higher yields, which increased from 14.5 t/ha/yr to 22.5 t/ha/yr. Therefore, it is clear that implementing GAP through sustainability certification can help increase the productivity of smallholders.

Although there is still no empirical study on the effectiveness of implementing GAP through MSPO on productivity, according to [29], increasing FFB yield up to 30 t/ha/yr can be achieved if smallholders implement GAP according to MSPO. Additionally, according to Mansor (as cited in [30]), it is estimated that the yield of FFBs will increase by at least

30% from the current productivity within three years after the implementation of GAP with technology adoption by MSPO-certified smallholders. In line with such studies, this study also expected the productivity of MSPO-certified oil palm smallholders to increase by implementing GAP in managing their plantations. Nevertheless, although GAP through MSPO promotes increased productivity, the effectiveness of GAP in delivering the well-being of smallholders in oil palm production areas still needs to be determined.

According to [31], well-being is a combination of good feelings that consists of positive experiences, having purpose in actions, and positive relationships. In [32], five indicators of well-being were suggested, namely positive emotions, engagement, relationships, meaning, and achievement (PERMA). These indicators reflect human nature. However, according to [33], sustainable well-being can be achieved through economic and social well-being. Figure 2 shows the sustainable well-being chart introduced by [33] which involves humans (people and community) and the environment (awareness, participation, and lifestyle).

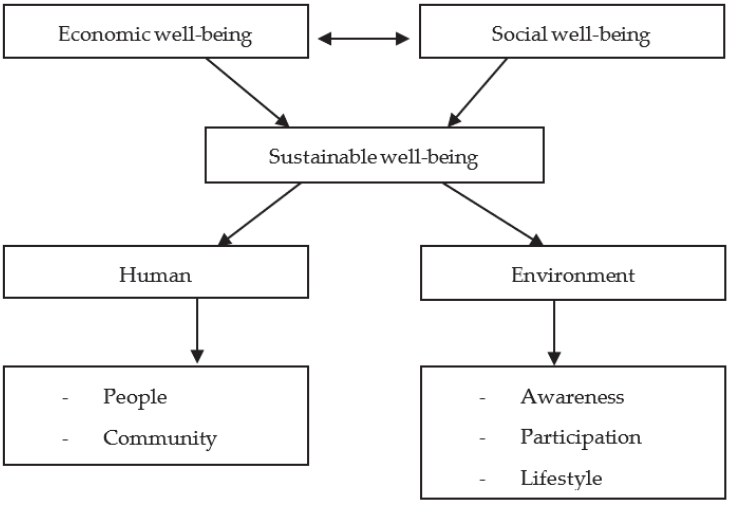

Figure 2. Well-being sustainability flow chart.

Since well-being is key to productivity [34], it is not limited to smallholders. The authors of [35] found that factors such as technology, optimal resources, insurance, market pricing, and tax policy will first impact smallholders' economic well-being and, subsequently, their social well-being. However, previous studies often relate the Sustainable Development Goals (SDGs) when discussing the well-being of smallholders, such as [36–38], which include the well-being of oil palm smallholders [39–42]. The SDGs comprise 17 goals, among which are to end poverty, preserve the planet, and ensure that all people live in peace and harmony by 2030 [43]. According to [44] smallholder palm oil, especially in Indonesia, played a role in achieving 13 goals out of the total SDG goals. Furthermore, the SDGs emphasise that sustainable development must balance social, economic and environmental considerations. For example, the literature review by [40] discussed the impact of palm oil on social, economic, and environmental aspects in addition to health and biodiversity across 234 articles. The study also discussed future strategies based on the SDGs for each of the effects found.

The field of research began to be developed by relating the impact of sustainability certification to the well-being of oil palm smallholders, considering that various certifications had been introduced. Among the palm oil sustainability certifications often used by the world palm industry are those issued by the RSPO, International Sustainability and Carbon Certification (ISCC), Indonesia Sustainable Palm Oil (ISPO), and MSPO. However, most previous studies discussed the impact of RSPO and ISPO on the well-being of oil palm

smallholders, such as [39,45,46], with no study on MSPO. Notably, most of the research results found that sustainability certificates help to improve the well-being of oil palm smallholders [45–47].

Furthermore, most previous studies discussed the impact of the oil palm industry on smallholders in terms of poverty and environmental problems, which are important indicators of their well-being [41,45,48–50]. In principle, the income earned by oil palm smallholders can improve households' living standards, eventually ending poverty. A study by [51–53], conducted using data from Malaysia, showed that oil palm cultivation positively affected smallholders' income. This was also found to be the case in Indonesia by [54–57], one of the two countries which are the world's largest palm oil producers. Other producing countries have also proven that oil palm cultivation can increase income and eliminate poverty, such as Ghana [45] and Guatemala [58]. Although the increase in income and poverty can be reduced, the environment's well-being is often at risk.

The environmental issues the oil palm industry faces have negatively impacted the well-being of smallholders and the local community. In addition, palm oil production activities in farms, such as using excessive fertilisers, inefficient wastewater management, using gasoline to kill weeds, and so on, performed by smallholders [59], will harm the environment and humans. Furthermore, according to [9], burning forests and peat land to prepare land for oil palm cultivation will cause the release of carbon dioxide (CO_2), affecting the health of smallholders and local communities. Therefore, GAP is expected to solve the dilemma, curbing environmental issues caused by the oil palm industry, especially those affecting smallholders, in addition to increasing their income and, subsequently, their well-being.

This study aims to (i) measure the smallholder's well-being index, (ii) compare the well-being index by states in Malaysia, and (iii) analyse the relationship between GAP implementation, productivity, and well-being. For objective (iii), this study made the following hypotheses:

Hypothesis 1 (H1). *GAP has a positive correlation with productivity.*

Hypothesis 2 (H2). *Productivity has a positive correlation with well-being.*

This study focuses on the well-being of smallholders, specifically Independent Smallholders (ISHs) who have obtained the MSPO certificate. There are two types of oil palm smallholders in Malaysia: organised smallholders and ISHs. Farm management for organised smallholders is better than that for ISH because they are regulated by several agencies (for example, FELDA, FELCRA, and RISDA), and usually, farm preparation materials and assistance are provided by these agencies. Therefore, they will receive wages monthly even if there is no production that month. On the other hand, compared to organised smallholders, the farm management of ISHs is poor because, according to Mansor (as cited in [23]), from 400 ISH, only 26% apply GAP.

2. Materials and Methods

2.1. Study Area

This study used a quantitative approach to accurately measure respondents' behaviour and levels of knowledge [60]. The population of this study was ISHs with MSPO certification. As of 2020, 129,307 ISHs have obtained MSPO certification (see Table 1). MSPO certification for ISHs is achieved by establishing a Sustainable Palm Oil Cluster (SPOC). A SPOC is established by grouping ISHs into several small clusters, with between 1000 and 2000 ISHs in each cluster [61]. Therefore, each ISH under the same SPOC will be jointly certified under one MSPO certificate. As a result, 162 SPOCs have been formed. Figure 3 shows the distribution of SPOCs in Peninsular Malaysia, Sabah, and Sarawak.

Table 1. Number of MSPO-certified Independent Smallholders by area.

Areas	Number of MSPO-Certified Independent Smallholder								
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total**
Peninsular	-	82	113	438	776	4142	15,732	56,798	78,081
Sabah	-	-	42	42	113	1021	3418	16,758	21,394
Sarawak	-	-	233	233	521	869	7670	20,772	29,832
Total	-	82	155	480	1410	6032	26,820	94,328	129,307

Note: MSPO was launched in 2013; there was no certificate ownership by ISHs in this year.

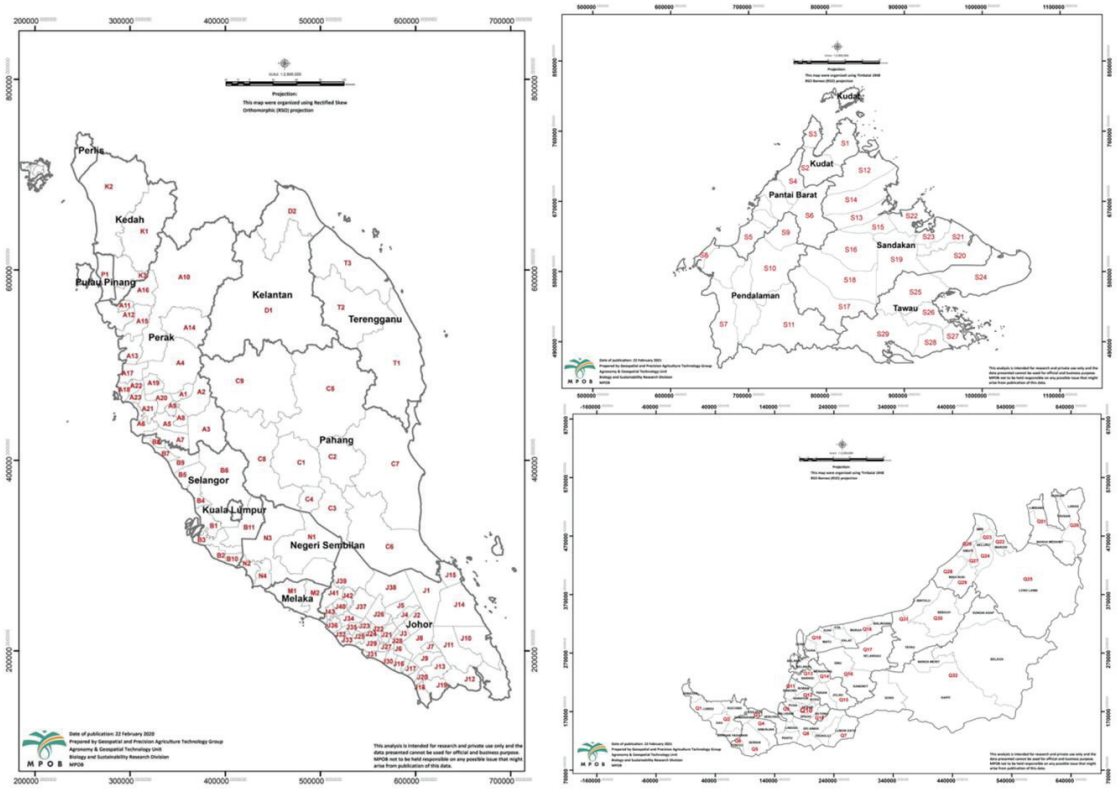

Figure 3. SPOC distribution in Peninsular, Sabah, and Sarawak, Malaysia. Source: Reproduced from [61].

Purposive sampling (PS) was conducted on all the SPOCs. PS is also known as judgement sampling. This sampling involves the identification and selection of individuals or groups who are knowledgeable about the phenomenon of interest [62] and are willing to participate in the research by conveying their experiences and opinions in a clear, expressive, and reflective manner [63]. Therefore, the total population sampling (TPS) method was used for this study by selecting ISHs with experience and knowledge of GAP and who have MSPO certification. TPS is a method that involves all populations that meet criteria such as skill sets, experience, and others in the research conducted [18]. The study determined the minimum sample size by referring to [64,65]. Determination of the minimum sample size according to the method of [64] was determined by the equation below:

$$\frac{x^2 \cdot NP(1-P)}{(N-1)d^2 + x^2P(1-P)} = n \quad (1)$$

where n is the sample size, N is population size: 129,307, x^2 is chi-square value: 3.841, P is population proportion: 0.5 (95%), and d is estimation error (0.05). In numerical form, the equation will be:

$$\frac{3.841(129,307)0.5(1-0.5)}{(129,307-1)0.05^2+3.841(1-0.5)} = 381.83 = 382 \quad (2)$$

wherein, according to [65], the minimum sample size should be ten times the maximum number of arrows indicating latent variables in the constructed SEM structural model. Since the PLS–SEM framework in Figure 4 has 32 arrows, the minimum sample size for this study is 320 samples. Therefore, based on the determination of the sample size by [64,65], the study required a sample size of 320 to 382 for a total population of 129,307 ISHs with MSPO. A total of 564 ISH in Malaysia were interviewed and given a set of questionnaires related to the study. However, only 475 questionnaires were answered completely and used for analysis.

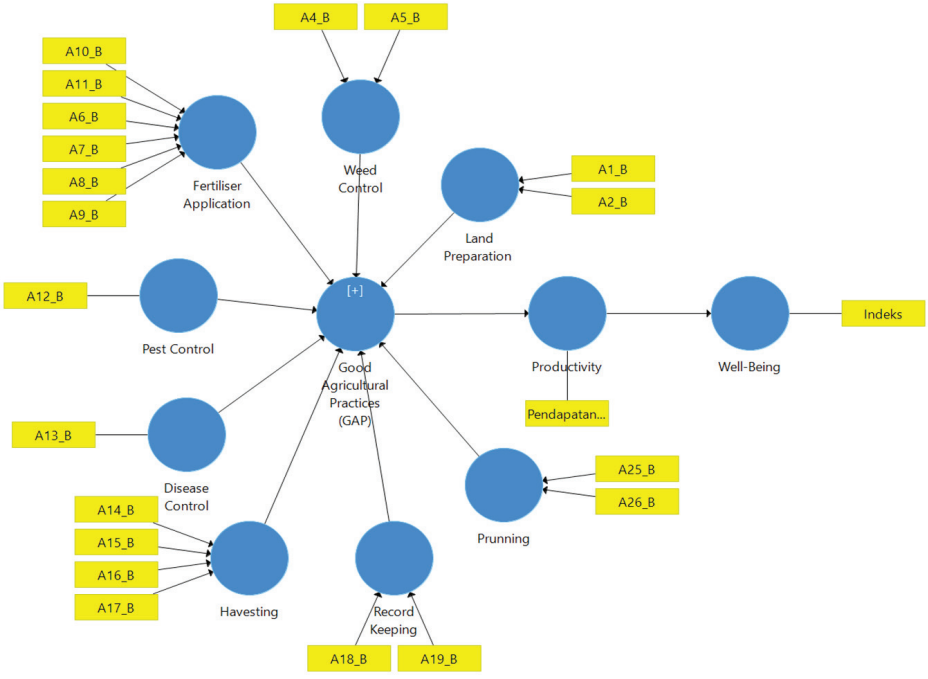

Figure 4. Path model on the relationship between GAP, Productivity and Well-being

2.2. Instrument and Data Collection

The study used primary data in which a questionnaire was the main instrument used for data collection. A semi-structured interview method with selected ISHs was conducted. The constructed questions were from discussions with the Malaysian Palm Oil Board (MPOB) and [66]. The questionnaire has three parts. The first part contains questions related to the respondent's demographic profile and farm information, comprising six questions. The questions are in the form of multiple-choice, two-choice, and open-ended questions. Further, the second part is a question related to the level of GAP implementation, which consists of nine constructs. The nine constructs are land preparation (two items), soil conservation (one item), weed control (two items), fertiliser application (six items), pruning (two items), disease control (one item), harvesting (four items), and record keeping (two items).

The final part is related to the perceptions of their level of well-being after achieving MSPO certification and comprises 50 questions. The questions are from eight constructs, namely income and wealth (ten items), employment and income (two items), living conditions (five items), health (eight items), work and life balance (nine items), education and skills (six items), environmental quality (four items), and subjective well-being (six items). For the second and third parts, the questions are in the form of a Likert scale on a five-point scale. In the second part, scale 1 represents not fully implemented, and scale five is fully implemented, while in the final part, scale one is strongly disagree, and scale five is strongly agree.

Initially, the questionnaire was constructed using Malay and then translated into English by an accredited translator. After that, the study ensured that every word was translated accurately and consistently reflects the initial questionnaire. Next, pre-testing was carried out before the actual data collection. The validity of the questionnaire for this study was evaluated by an MPOB officer and a lecturer from Universiti Utara Malaysia (UUM), an agricultural economics scholar. A total of seven (7) questionnaires were distributed to five (5) ISHs who had obtained MSPO certificates, and two (2) lecturers involved in the field of agricultural economics. Meanwhile, reliability was determined by using Cronbach's Alpha (α) test to determine whether the questionnaire could give the same answer to each population size and sample. The Cronbach's Alpha (α) results at this pre-testing stage showed a value of 0.70 and above, which means that the data obtained is good and effective for this study.

In order to ensure that data collection was done well, TUNAS (Tunjuk Ajar dan Nasihat Sawit) officers were appointed as enumerators to distribute questionnaires and interview respondents in each SPOC in Malaysia. A briefing on how to answer the questionnaire was performed in stages. The first stage involved ICS (Internal Control System) officers, who are the TUNAS officers' supervisors, to inform them of the needs of the study. At the same time, the ICS reviewed the questionnaire to ensure that the questionnaire was ready to be distributed. Then, the ICS explained the results of the briefing to their TUNAS officers. In the second stage, the briefing was given directly to TUNAS officials. This was done to ensure that TUNAS officers understood the needs of the study, and if there were any problems in implementing data collection, the problems could be solved earlier. Afterwards, the questionnaire was ready to be distributed to the actual respondents. The data collection was conducted from April to November 2022.

In addition, this study has obtained ethical approval, since this study is an interventional study involving humans. The Research Ethics Committee of Universiti Kebangsaan Malaysia (REC-UKM) is the authority that provided approval for the research, and the code is UKM PPI/111/8/JEP-2023-018.

2.3. Data Analysis

This study had two steps to achieve its objectives. First was a Principal Component Analysis (PCA) to determine the well-being index [67,68] with STATA 14, and the second was Partial Least Squares Structural Equation Modelling (PLS–SEM) to analyse the relationship between dependent and independent variables [69]. PCA was used to build a new construct to form a well-being index. Before PCA is done, some conditions need to be met: the data does not require normality and homoscedasticity. A sufficient number of data obtained by PCA adequately represent the theoretical construct under study. It can be defined by: (i) the relative values of the eigenvalues (variances of the components); (ii) the total variance explained by the components, which are all components with eigenvalues greater than one that should be retained. The justification is that if all variables were uncorrelated, each eigenvalue (λ) would equal 1. If $\lambda < 1$, the component provides less information than the original variable and should not be used [70].

The well-being index was constructed from 50 items measured using a 1–5 Likert scale indicating the degree of agreement with increasing well-being. A Likert scale measures the indicators from 1 (strongly disagree) to 5 (strongly agree). These items were formed into

eight constructs: income and wealth (IW), employment and income (EI), residential (R), work and life balance (WB), health (H), education and skills (ES), environmental quality (EQ), and subjective well-being (SW). Because the construct score generated by PCA might have a positive or negative value, normalisation was carried out by transforming the value using the rank of percentiles to the index, in which the score ranged from 0 to 1. This situation made the total variance explained by the components exceed 50%, which meets the requirements of PCA. Then, indicator scores were assigned with weights derived from the PCA to estimate the well-being index (WI) as below:

$$Well - being\ index = \sum_{i}^{n} W_i X_i \quad (3)$$

where W_i is the weight of the indicator, X_i is the indicator score, and n is the number of indicators.

In the second step, PLS–SEM analysis was used in this study. SEM was chosen because it can show a clear relationship between GAP implementation, productivity, and well-being. Moreover, it can give a simple evaluation compared to other methods, even though the model developed is complex and involves many linear equations [71]. The study uses "smart" partial least squares (SmartPLS) software, version 3.0. SmartPLS, one of the most popular and powerful statistical techniques available to calculate path estimates and model parameters without the concern of normality of data [72], is suitable for both large and small samples. In addition, this study evaluates items for each construct developed. Therefore, SmartPLS is suitable for that analysis.

SmartPLS consists of the measurement model and the structural model properties of data. The measurement model for formative indicators uses variance inflation factor (VIF) and outer weight. The VIF test was used to assess the multicollinearity issue. If the VIF value is less than 3.33, it indicates no multicollinearity [73]. At the same time, the outer weight of the items should be significant [65]. If a particular outer weight is insignificant (p-value < 0.050 and t-value < 1.96), then outer loading and the minimum required value of 0.50 is checked. That indicator is removed if both weights are not significant and outer loadings are less than 0.50.

The structural model was assessed by examining the values of the coefficient of determination (R2), predictive relevance (Q2), and path coefficients. The value of Q2 must be more than 0, which indicates predictive relevance; Q square: 0.02, 0.15, 0.35 for weak, moderate, and strong effects of predictive relevance [74]. The path coefficients should be greater than 0.10 or 0.20 [75] with t-statistics and a significant level [76]. A two-tailed T-test is considered with 1.645, 1.96, and 2.576 critical values of t at a significant level (p-value) of 0.1, 0.05, and 0.01, respectively.

3. Results and Discussion

3.1. Profile of Respondent

The information presented in Table 2 shows that the majority of respondents had an SPM and MCE level of education (39.4%). They were followed by respondents with SRP, LCE and equivalent (18.1%), and UPSR and equivalent (12.6%) education levels. Then, most respondents had experience managing oil palm production for 11 to 20 years, at 40.0%, and 1 to 10 years, at 32.8%. Next, they planted oil palms, starting in 1957, on their farms certified by MSPO, and most respondents planted them from 2001 to 2010, at 38%. Therefore, most of the palm trees were under 20 years old, at 85.7%, and most of the respondents earned income below MYR 20,000, at 50.3%. Regarding farm size, the majority were 1.01–10.00 acres (76.2%).

Table 2. Profiles of respondents.

Information	Frequency	%
Level of education:		
Non-formal education	27	5.7
UPSR and equivalent	60	12.6
SRP, LCE, and equivalent	86	18.1
SPM and MCE	187	39.4
Skills certificate	15	3.2
Diploma/matriculation	51	10.7
Degree	36	7.6
Masters	13	2.7
Experience managing oil palm (year):		
1–10	156	32.8
11–20	190	40.0
21–30	79	16.6
41–50	34	7.2
51–60	11	2.3
61–70	5	1.1
Year planting started		
1957–1990	43	9.1
1991–2000	83	17.5
2001–2010	183	38.5
2011–2018	166	34.9
Age of palm oil (year):		
4–10	174	36.6
11–20	233	49.1
21–30	67	14.1
31–40	1	0.2
Income after MSPO (RM):		
1000–10,000	136	28.6
10,001–20,000	108	22.7
20,001–30,000	84	17.7
30,001–40,000	34	7.2
40,001 and above	113	23.8
Farm size (Ha):		
0.10–1.00	80	16.8
1.01–10.00	362	76.2
10.01–20.00	19	4.0
20.01–30.00	10	2.1
30.01–40.00	4	0.8

3.2. Principal Component Analysis (PCA)

Table 3 shows the mean value exceeded 2.50, meaning respondents "agree" with each construct statement. The Pearson correlation matrix for the eight constructs used in the PCA analysis is shown in Table 4. Statistically significant correlations were observed for all variables ($p < 0.01$).

Table 5 contains the eigenvalues for the first four principal components and the eigenvectors related to each of the principal eigenvalues. Based on Kaiser's criterion [70], only the components with eigenvalues greater than one could be maintained. Thus, in our analysis, we kept only one PC ($\lambda 1 = 5.797$). As regards the covering proportion, those four principal components preserved roughly 0.725 or 72.5% of the total variance. Therefore, a remarkable dimensional reduction was achieved if the information from the first component was used. Kaiser–Meyer–Olkin (KMO) shows 0.9401, indicating the variance proportion in the adequate construct. The coefficients of the eight constructs in the first principal component after standardisation are given in Table 6. It can be observed that all coefficients

are positive and almost equal, implying that the five variables participate with equal weights to the formation of the first principal component and, therefore, to the proposed well-being index having the formula:

$$Well-being\ index = 0.3664_{IW} + 0.3118_{EI} + 0.3613_{R} + 0.3393_{WB} + 0.3826_{H} + 0.3650_{ES} + 0.3489_{EQ} + 0.3487_{SW} \quad (4)$$

Table 3. Mean construct of well-being.

Construct	Mean
Income and wealth (IW)	3.859
Employment and income (EI)	3.735
Residential (R)	4.019
Work and life balance (WB)	3.804
Health (H)	4.115
Education and skills (ES)	4.248
Environmental quality (EQ)	4.085
Subjective well-being (SW)	4.457

Table 4. Correlation matrix of the eight constructs used in the PCA.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income and wealth (1)	1.0000							
Employment and income (2)	0.6677 *	1.0000						
Residential (3)	0.7918 *	0.6238 *	1.0000					
Work and life balance (4)	0.7062 *	0.5829 *	0.7166 *	1.0000				
Health (5)	0.7744 *	0.6275 *	0.7638 *	0.7108 *	1.0000			
Education and skills (6)	0.7050 *	0.5608 *	0.6855 *	0.6442 *	0.8413 *	1.0000		
Environmental quality (7)	0.6870 *	0.5939 *	0.6427 *	0.5891 *	0.7590 *	0.7465 *	1.0000	
Subjective well-being (8)	0.6615 *	0.5044 *	0.6845 *	0.6180 *	0.7656 *	0.7715 *	0.6930 *	1.000

* significant at level 0.01.

Table 5. Principal Components Analysis.

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	5.797	5.204	0.725	0.725
Comp2	0.593	0.144	0.074	0.799
Comp3	0.449	0.147	0.056	0.855
Comp4	0.302	0.019	0.038	0.893
Comp5	0.283	0.045	0.035	0.928
Comp6	0.238	0.043	0.030	0.958
Comp7	0.195	0.052	0.024	0.982
Comp8	0.143		0.018	1.000
Number of observations		475		
Number of components		8		
Trace		8		

Table 7 shows that the mean well-being index was 0.6190, and the mean level of well-being for ISHs (MSPO) was 61.90% in Malaysia. The index indicated that the well-being of those with MSPO certification is positive and acceptable. The finding corresponds with [41,42], which reported that oil palm smallholders had received many benefits through certifications such as MSPO and RSPO. There is no denying that oil palm smallholders have obtained many benefits by participating in being sustainably certified. However, given that 61.90% is slightly more than half, ISH's well-being and quality of life need to be continuously enhanced.

Table 6. Kaiser–Meyer–Olkin (KMO) and coefficient measure of sampling adequacy of the first principal component for the eight constructs.

Variable	KMO	Coefficient
Income and wealth (IW)	0.9360	0.3664
Employment and income (EI)	0.9555	0.3118
Residential (R)	0.9335	0.3613
Work and life balance (WB)	0.9619	0.3393
Health (H)	0.9263	0.3826
Education and skills (ES)	0.9187	0.3650
Environmental quality (EQ)	0.9549	0.3489
Subjective well-being (SW)	0.9475	0.3487
Overall	0.9401	

Table 7. Analysis mean of well-being index according to state.

States	Index
Sarawak	0.6619
Sabah	0.7345
Johor	0.5096
Perak	0.6104
Pulau Pinang	0.5246
Kedah	0.4904
Selangor	0.6387
Negeri Sembilan	0.6469
Melaka	0.3264
Terengganu	0.7217
Pahang	0.6295
Kelantan	0.6123
Overall	0.6190

Furthermore, the highest ISH's well-being was in Sabah (0.7345), followed by Terengganu (0.7217) and Sarawak (0.6619). Conversely, the lowest well-being level was of ISHs in Melaka (0.3264). The result is interesting, given that ISHs in Sabah and Sarawak face greater challenges implementing GAP and being sustainably certified. It was reported in [77] that most smallholders in Sabah and Sarawak have limited access to a broader market, making them dependent on traders willing to travel long distances to collect harvested FFBs. Additionally, smallholders in both states need more support in getting access to seeds, fertiliser, and a workforce.

3.3. PLS–SEM Analysis

3.3.1. Measurement Model

Table 8 shows the mean value exceeded 2.50, meaning respondents "agree" with each construct statement. Table 8 also show the VIFs of all the indicators of land preparation, soil conservation, weed control, fertiliser application, pruning, pest control, disease control, harvesting, and record keeping, ensuring that multicollinearity is not present. The result shows that all VIF values are below the threshold limit of 3.33; thus, there is no issue of multicollinearity of the indicator with the construct. Table 8 also shows the significance and relevance of the formative indicators. In the bootstrapping procedure of 2000 subsamples, the results indicated that all outer weights are significant, with t-statistics > 1.96 and p-value < 0.05, except for two indicators on fertiliser application and one indicator on harvesting. However, all the indicators were retained because the outer loadings exceeded 0.50.

Table 8. Mean, standard deviation, and weight loadings.

Construct/Item	Mean	Weight Loading	t-Value	*p*-Value	VIF	Outer Loading
Land Preparation:						
1. The harvest lane is in good condition	4.385	0.755	10.873	0.000	2.889	0.986
2. The road is in good condition	4.352	0.286	3.803	0.000	2.889	0.896
Weed Control:						
1. Palm oil tree is free from weeds (in radius 2 m)	4.305	0.583	11.1	0.000	1.600	0.908
2. No parasitic plants on the oil palm stems	4.116	0.531	9.723	0.000	1.600	0.888
Fertiliser Application:						
1. Palm oil trees are fertilised in proportion	4.324	0.09	1.381	0.168	3.724	0.821
2. Palm oil trees are fertilised according to nutritional needs	4.282	0.195	2.797	0.005	3.609	0.835
3. Fertiliser is spread around the tree/in the frond pile aisle	4.499	0.438	6.498	0.000	2.694	0.925
4. Fertilising frequency for young trees (<3 years old)	4.221	0.157	2.01	0.045	3.265	0.784
5. Fertilising frequency for mature trees (>4 years old)	4.312	−0.014	0.207	0.836	3.498	0.773
6. Fertiliser is sown within 1 month after receipt/purchase	4.438	0.299	5.676	0.000	1.926	0.821
Pruning:						
1. Pruning the fronds according to the age of the tree	4.322	0.659	5.832	0.000	2.151	0.949
2. Pruned fronds are arranged according to contours or rows	4.425	0.428	3.52	0.000	1.979	0.875
Pest Control:						
1. Farms are free from pest attacks	4.122	1.000	-	-	1.000	1.000
Disease Control:						
1. Farms are free from Ganoderma	4.232	1.000	-	-	1.000	1.000
Harvesting:						
1. Harvesting the ripe FFBs only	4.674	0.296	3.326	0.001	2.765	0.87
2. The stalks are cut (≤5 cm)	4.568	0.396	5.276	0.000	2.394	0.902
3. All the loose fruits are collected	4.581	0.334	4.994	0.000	2.122	0.856
4. FFB and loose fruits are delivered in 24 h	4.691	0.121	1.376	0.169	2.756	0.673
Record Keeping:						
1. Keeping a complete record book	4.215	0.505	4.006	0.000	2.951	0.948
2. Record plantation activity immediately	4.084	0.545	4.385	0.000	2.951	0.956

3.3.2. Assessment Structural Model of Second-Order Constructs

In this study, GAP was specified as a second-order formative construct that comprised eight first-order formative constructs (disease control, fertiliser application, harvesting, land preparation, pest control, pruning, record keeping, and weed control). All the path coefficients of all factors in the first-order to good agricultural practices were greater than

0.10 and significant at p-value < 0.01, meaning all factors were essential for building good agricultural practices of palm oil smallholders (Table 9).

Table 9. Assessment of second-order constructs.

Relationship	Path Coefficients (β)	SD	T-Statistics	p-Values
Disease Control → GAP	0.151	0.006	25.862	0.000
Fertiliser Application → GAP	0.190	0.006	32.070	0.000
Harvesting → GAP	0.179	0.005	35.337	0.000
Land Preparation → GAP	0.177	0.006	27.577	0.000
Pest Control → GAP	0.158	0.005	29.203	0.000
Pruning → GAP	0.131	0.011	11.838	0.000
Record Keeping → GAP	0.153	0.006	25.217	0.000
Weed Control → GAP	0.185	0.005	37.155	0.000

3.3.3. Assessment Structural Model of Hypothesis Test

The R^2 value, the statistical significance of the Q^2 value, and path coefficient values were used to measure the structural model's overall explanatory capacity of constructs. Figure 5 illustrates the structural model's output. Table 10 shows that the R^2 obtained for member activism is 1.000, which means that 100% of the variance in GAP by all factors is in the second order, whereas the R^2 obtained for productivity is 0.006, which means that GAP explains 0.6% of the variance in productivity. Further, the R^2 obtained for well-being is 0.016, which means that 1.6% of the variance in well-being is explained by productivity. The results for Q^2 for each construct are 0.447 (GAP), 0.004 (productivity), and 0.015 (well-being). Both constructs yielded a Q^2 of more than 0.0, thus showing that the model has predictive relevance.

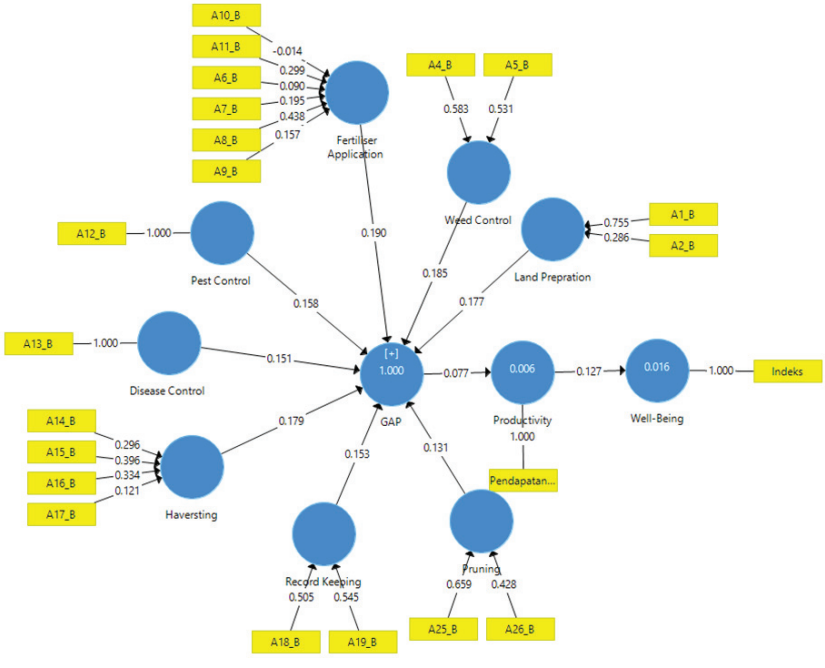

Figure 5. Output Model.

Table 10. R square and Q square.

Construct	R Square	R Square Adjusted	Q Square
GAP	1.000	1.000	0.447
Productivity	0.006	0.004	0.004
Well-being	0.016	0.014	0.015

Furthermore, Table 11 and Figure 5 show the path coefficients along with their t-values and *p*-values. The relationship between GAP and productivity shows that the effect of GAP and productivity (β = 0.077; t-value = 1.826, *p*-value = 0.068) is considered positive and significant, indicating that H1 is supportive. This result supports [21], which states that sustainable agricultural production will increase productivity (income). Further, the relationship between productivity and well-being with a 0.127 value of path coefficients (β) (t-value = 3.040; *p*-value = 0.002) is considered positive and significant, indicating that H2 is supportive. It explains that productivity can directly enhance well-being. This result supports [51,52], who state that economic productivity (income) can increase the well-being of palm oil smallholders in Malaysia, and where one of the impacts of MSPO is shown.

Table 11. Hypothesis testing.

Relationship	Path Coefficients (β)	SD	T-Statistics	*p*-Values
Relation: GAP–Productivity	0.077	0.042	1.826	0.068
Relation: Productivity–Well-being	0.127	0.042	3.040	0.002

3.4. Limitations of the Study and Areas for Further Studies

There were several limitations when this study was conducted. First, respondents in rural areas, especially in the states of Sabah and Sarawak, prefer to be interviewed using their native language. This caused the data collection process to take a long time because the enumerator had to explain the questions one by one. The study also found a limitation in the PLS–SEM analysis when the data was analysed; this analysis cannot be applied when structural models contain causal loops or circular relationships between the latent variables.

Therefore, the study suggests that for future studies, the chosen analysis must have the strength to diversify the research findings, which can bring innovation when data analysis activities are carried out. In addition, index measurement can be done according to [33], which classifies well-being into economic and social well-being to see their well-being from various aspects and as an entirety.

4. Conclusions

Palm oil GAP in Malaysia is the basis for increasing productivity and is a requirement for MSPO [23]. Although GAP through MSPO promotes increased productivity, the effectiveness of GAP in delivering the well-being of smallholders in FFB production areas still needs to be determined. Therefore, an extensive literature review was undertaken to understand GAP's influence on ISHs' productivity and well-being with MSPO certification. As a result, much literature has discussed how good agricultural practices and certification benefit and increase crop productivity [21,27,28]. Nevertheless, some literature reflected otherwise, with results in sustainability certification not necessarily bringing a positive outcome [41]. Therefore, this research was undertaken to (i) identify measures of the smallholder's well-being index, (ii) compare the well-being index by states in Malaysia, and (iii) look at the relationship between the implementation of GAP, productivity, and well-being.

The study used quantitative methods and questionnaires to collect data for 564 ISHs in Malaysia. Then, the study analysed the data using PCA and SEM methods to achieve the objectives. The results showed that when using PCA, Malaysia's ISHs' well-being

index was reported at 61.86%, and the ISHs in Sabah had the highest well-being index (0.7345). The study also found that GAP can increase productivity and directly increase ISHs' well-being. Therefore, the ISHs must improve their knowledge, skills, and attitude to ensure that GAP implementation succeeds. This study also provides valuable input to stakeholders such as MPOB, MPOCC, and the Ministry of Plantation and Commodities to ensure that the well-being of ISHs is constantly improved and, at the same time, the sustainability of the oil palm industry can be guaranteed.

Author Contributions: Conceptualization, N.A.b.M.S., N.H.M.S., N.C., S.S., K.M.S. and K.H.; methodology, N.A.b.M.S., N.H.M.S. and M.S.S.; software, M.S.S.; validation, K.M.S. and K.H.; formal analysis, N.A.b.M.S., N.H.M.S. and M.S.S.; investigation, N.A.b.M.S., N.H.M.S. and K.H.; data curation, N.A.b.M.S. and N.H.M.S.; writing—original draft preparation, N.A.b.M.S.; writing—review and editing, N.H.M.S., M.S.S., N.C. and S.S.; visualization, K.M.S. and K.H.; supervision, N.H.M.S.; project administration, N.H.M.S., N.C., S.S., K.M.S. and K.H.; funding acquisition, N.H.M.S., N.C. and S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by MPOB-UKM Endowment Chair Grant, Malaysia, grant number: EP-2020-031.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, ICH and Malaysian GCP Guidelines, and approved by the UKM Research Ethics Committee (UKM PPI/111/8/JEP-2023-018 and 10 February 2023).

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to might containing information that could compromise the privacy of research participants.

Acknowledgments: We would like to express our deep gratitude to the Malaysian Palm Oil Board (ICS & TUNAS) for their able guidance and support in completing this project.

Conflicts of Interest: The authors declare no conflict of interest.

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Insecticide Use by Small-Scale Ugandan Cassava Growers: An Economic Analysis

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Abstract: Cassava is the second most important source of calories in Sub-Saharan Africa. It is subject to economically important yield losses from viral diseases, including cassava brown streak disease and cassava mosaic disease. These diseases are vectored by cassava whitefly, so improved approaches for whitefly and disease control are needed to enable smallholder farmers to protect their cassava crops. To investigate the economic viability of insecticide applications against whitefly, the effect of four insecticide application regimes on three cassava genotypes (NASE 3, NASE 12, MKUMBA) and a local landrace were evaluated, for different farmer groups. Data were collected from researcher–farmer managed fields and descriptive statistics were analyzed. Insecticide and personal protective equipment were the major costs for those farmers that applied insecticide and the dipping treatment had a marginal rate of return of 1.66 (166%), demonstrating that this option was the most profitable and effective. While insecticide users incurred more production costs, they also accrued more profit than non-insecticide users, especially if insecticide was applied at early stages of cassava growth. There is a clear need, therefore, to strengthen the commercialization of cassava crop through plant protection measures such as judicious insecticide application on susceptible varieties, so as to increase yield and crop quality.

Keywords: cassava whitefly; insecticide; whitefly damage; marginal rate of return; benefit cost ratio; cost function

Citation: Bayiyana, I.; Bua, A.; Ozimati, A.; Mugisha, J.; Colvin, J.; Omongo, C.A. Insecticide Use by Small-Scale Ugandan Cassava Growers: An Economic Analysis. *Agriculture* **2023**, *13*, 1043. https://doi.org/10.3390/agriculture13051043

Academic Editors: Hung-Hao Chang, Pei-An Liao and Jiun-Hao Wang

Received: 29 March 2023
Revised: 24 April 2023
Accepted: 10 May 2023
Published: 11 May 2023

1. Introduction

Cassava in Uganda is the second most important staple food crop after bananas. It is mostly grown by smallholder farmers and contributes approximately 22% of the total farmer households' cash incomes [1]. The crop is traded domestically as fresh roots, dry chips, grits and high-quality flour (HQF). It provides 20% of the total national calorie intake with an annual per capita consumption estimated at 119 kg [2]. It is largely grown by 3.9 million smallholder farmers in all regions, in descending order, in the Northern, Eastern, Central and Western regions [3]. The crop is available all year round and contributes to essential nutrients such as carbohydrates, vitamins and minerals [4]. Cassava yields, however, are adversely affected by pests such as whiteflies, mites, thrips and scale insects, which cause significant losses through their feeding damage leading to low cassava productivity (leaves and roots) [5]. The two viral diseases, cassava mosaic disease (CMD) and cassava brown streak disease (CBSD), reduce yields by over 40% (i.e., 42%—CMD; 55%—CBSD) in susceptible varieties [6–8].

The African cassava whitefly, *Bemisia tabaci* SSA1, and its outbreaks are responsible for serious crop yield losses in East and Central Africa resulting in hunger, recurrent famines and annual financial losses of more than US$1.25 billion [9–12]. Moreover, areas experiencing economically damaging populations of the African cassava whitefly are continuing to expand [13]. Cassava viral disease incidence is increasing rapidly at a time when cassava is becoming a commercial crop and a stimulant for agro-industrial growth in Uganda [4,14,15]. The rapid increase in disease incidence is also associated with the unprecedented increase in the whitefly vector populations [16–19].

Cassava mosaic disease and CBSD have been managed previously by use of virus-tolerant planting materials with less focus on the whitefly vector [20]. As a way of combating the two viral diseases by targeting the whitefly, researchers at the National Crops Resources Research Institute (NaCRRI), Namulonge, initiated farmer participatory research using insecticides consisting of four treatment regimes (i.e., dipping, early protection, no early protection and no protection) on farmer-managed fields in the districts of Pallisa, Kamuli and Luwero (2019), and Buikwe, Bugiri and Serere (2020). The aim was to evaluate the effectiveness of the protection offered by a widely available systemic insecticide (imidacloprid) in the management of whiteflies for sustainable food security in Sub-Saharan Africa (SSA).

Omongo et al. [21] reported that there were significant root and stem yield differences between chemically treated and non-treated cassava crops. The yields were 40% and 55% lower in non-treated crops for cassava roots and stems, respectively [21]. These yield gaps are a real concern for food security, cassava agro-industrialisation and the seed systems, delivered via cassava seed entrepreneurs. It is because of these yield differences that we were prompted to perform an economic analysis of the different insecticide application treatments, so as to discover the most appropriate recommendations to make to farmers.

To enhance farmers' adoption, cassava pests and disease control through insecticide applications needs to be cost-effective and practical [22]. This study investigated the economic viability of different insecticide application treatments used by smallholder farmers in Uganda to control whiteflies in cassava crops. To date, there have been several attempts to reduce whitefly populations [23–25], but these studies did not include analyses of the costs and benefits involved.

This study therefore, conducted an empirical investigation to address the following research questions: (i) What were the costs and benefits associated with the different levels of insecticide application to control whiteflies in cassava production? (ii) What were the gross margins for the different insecticide application treatments? (iii) Can whitefly-resistant varieties such as MKUMBA be used as an additional control measure to combat super-abundant whitefly populations? (iv) What were the marginal rates of return for the different insecticide application treatments?

2. Materials and Methods

The study was conducted in six cassava-growing districts: Pallisa, Kamuli and Luwero for year one (2019), and Buikwe, Bugiri and Serere for year two (2020) because the cassava whitefly, CMD and CBSD were identified as problems in these districts. Pallisa, Kamuli, Bugiri and Serere are located in the southern Lake Kyoga Plain agroecology in Eastern Uganda, which is drier, while Luwero and Buikwe are in the Lake Victoria Crescent agroecology in Central Uganda which is wetter and more humid (Figure 1).

The trials consisted of five application treatments of imidacloprid insecticide for each cassava variety. Imidacrorid insecticide was used because it is a common, affordable and recommended systemic insecticide in the Ugandan market that is being used to control sucking insects on food crops, orchards, ornamentals, cotton and other crops in the country. This paper will provide the first well-researched evidence for its successful use in cassava to control whiteflies. The treatments were as follows: (i) DP/dipping = no spraying at all but the cuttings are dipped in chemical for some hours before planting (ii) EP/early protection = dipping plus spraying once every 2 months up to 4 months after planting

(iii) NEP/no early protection = no dipping but insecticide was applied at 5 and 7 MAP months after planting (iv) NP/no protection = no chemical application at all (v) LP/long protection which consisted of dipping, spraying at 2, 4 and 6 MAP. Prior to planting, cassava cuttings measuring 0.5 m under DP, EP and LP treatments were stacked upright in a plastic basin and drenched in a diluted solution of imidacloprid 200 SL at 3 mls/L for 5 days. Cuttings planted in the "no protection" (control) plots were drenched in tap water to balance any effect in terms of sprouting of the cuttings because of immersion in liquid. After planting, foliar application of imidacloprid 200 SL was carried out using different spray regimes to vary the length (duration) of protection.

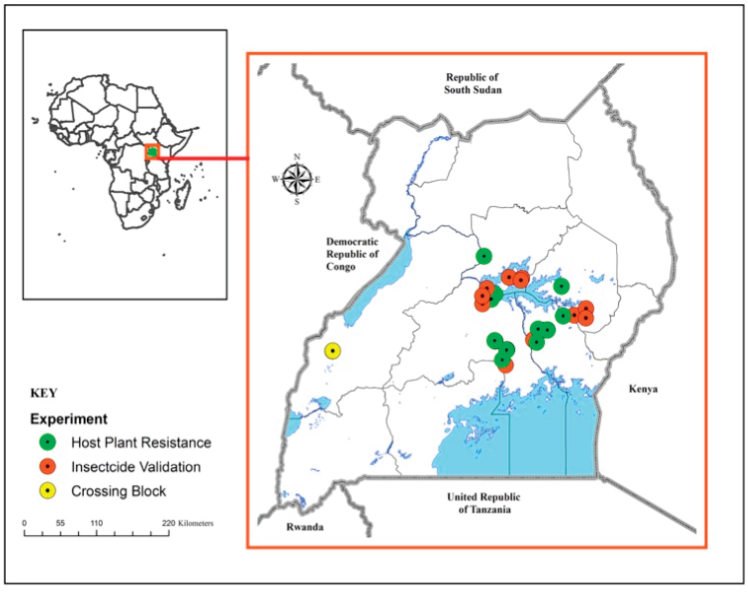

Figure 1. Technology validation sites.

This study is the first of its kind in Uganda to critically investigate the timed application of insecticide to control whitefly in cassava. The choice of application intervals was our well-thought-out decision based on the findings of earlier research on whitefly population dynamics which showed that population is highest in the first four months of cassava growth. Through its dual role as a vector and a pest, this is also the period in which whitefly causes high feeding damage and spread of the viral diseases. This study will therefore provide the first recommendation of the spraying intervals/period which is economical to effectively control whitefly in cassava. Spraying was only carried out when there was little or no wind in order to avoid drift. The foliar treatments were carried out using a CP15 backpack knapsack sprayer (15 L-capacity) with a hydraulic cone nozzle. The dosage of imidacloprid 200 SL used was 30 mls per CP15 backpack in year one. In year two, the LP regime was eliminated, because it was clearly too costly, leaving only four treatment regimes for the experiment.

The cassava genotypes used across trials were: NASE 3, NASE 12 and MKUMBA, plus a local popular check that varied from district to district, which were Kabwa/Matooke/Kalitunsi (Buikwe), Magana or China-0 (Bugiri) and Edyala (Serere). The selection of the 3 varieties was based on their differential response to *B. tabaci* infestation: MKUMBA is known to be resistant, NASE 3 is tolerant and NASE 12 is susceptible to whitefly infestation. We envisaged that insecticide application by dipping the cuttings prior to planting and spraying during the critical growth stage (1–4 months after planting) would demonstrate the effect and economics of insecticide protection for varieties which are resistant, tolerant

and susceptible. NASE 3 and NASE 12 have been commonly grown by farmers since their releases in 1993 and 2001, respectively. Meanwhile, MKUMBA is a recent introduction and proved resistant to whiteflies, hence was a good control treatment for the insecticide application experiment.

Each variety was exposed to all the treatments in separate plots of the same field. In total, there were 20 and 16 plots per field for trial 1 and trial 2, respectively. Each plot consisted of 36 plants. The plot sizes were 5 m by 5 m arranged in a randomized complete block design (RCBD) with a spacing of 1 m by 1 m between cassava plants.

Prior to farmer data collection, the different farmer groups received training on whitefly and the associated damage symptoms. These groups then collected data on the prevalence of whitefly, CMD and CBSD independently, in addition to those experimental data collected by the researchers. The different farmer groups (18 groups) acted as the replicates in the analyses of the farmer-collected data. The researchers collected data from the same farmer-participatory trials and demonstrations to test whether, or not, they generated substantial and clear benefits in terms of farmers' increased yields and income, as well as significantly reducing cassava whitefly populations and disease incidences.

The effect of the different insecticide regimes was evaluated in the plots at 1, 2, 4, 5, 7 and 12 months after planting (MAP) for whitefly infestation, CBSD foliar symptoms and CMD. At 12 MAP, harvesting was carried out and data were collected from the inner rows of each plot excluding the border rows because of undue agronomic benefits. The average plot size for the inner plot consisted of 16 plants. The severity of CBSD root necrosis was assessed using a scale of 1–5 [26–28], where 1 = no apparent root necrosis, 2 = less than 5% of root necrotic, 3 = 5–10% of root necrotic, 4 = 10–25% of root necrotic, mild root constriction and 5 = >25% of root necrotic with severe root constriction.

For CMD, the assessment scale used was, 1 = un-affected shoots, or no symptoms observed, 2 = mild chlorotic pattern on most leaves, mild distortions at the bases of most leaves, while the remaining parts of the leaves and leaflets appear green and healthy, 3 = pronounced mosaic pattern on most leaves, narrowing and distortion of the lower one-third of the leaves, 4 = severe mosaic distortion of two-thirds of most leaves and general reduction in leaf size, and some stunting of shoots, and 5 = very severe mosaic symptoms on all leaves, distortion, twisting and severe leaf reduction in most leaves accompanied by severe stunting of plants [26,29].

2.1. Data Analysis

To determine the economic performance of different treatments, a cost–benefit analysis (CBA) was conducted, as described by Dewri et al. [30] and Weimer [31]. The cost–benefit analysis seeks to place monetary values on both the inputs (costs) and outcomes (benefits) [32].

To achieve this, operations realized were specified in the three stages of production:

- Pre-sowing (ploughing or other tillage, dipping of cuttings and planting)
- Husbandry (insecticide application and weeding)
- Harvest (crop harvest, product sorting and grading)

For each of the alternatives, the type of equipment involved, the labor (man hours), the quantity and type of inputs applied, as well as their open market prices, were specified.

Following Dewri et al. [30], we use the benefit–cost ratio (BCR) together with the marginal rate of returns (MRR) to arrive at the best (most cost effective) treatment. The BCR helps to derive the ratio of whitefly control alternatives' benefits versus costs, which helps to determine the viability and value that can be derived from an investment. All things being equal, farmers should be willing to accept a treatment if the BCR of that treatment is greater than the minimum acceptable BCR of 1.5 (BCR > 1.5). A treatment with a ratio greater than 1 (BCR > 1) is considered economically viable and BCR =1 is the breakeven point. Nonetheless, due to the cost of capital and inflation the minimum acceptable BCR for an investment to be considered viable is a BCR of 1.5. BCR involves summing up the total discounted benefits for a given alternative over its entire duration, which is one year for cassava, and dividing it by the total discounted costs for that alternative. The advantage of

using BCR is that it helps to compare various options in a single term and helps in deciding faster which options should be preferred or rejected. Unlike the net present value (NPV) model which helps to determine whether a treatment should be invested in or not, the BCR model helps to solve the dilemma of choosing between two or more treatments based on the BCR, whereby the one with the highest BCR is chosen as the most worthwhile option [33]. In the process, the gross margins for the different alternatives were also computed. The gross margin is the difference between the gross farm income (total revenue) and the costs incurred during production (total variable cost). The analysis to achieve gross margins was carried out as follows:

$$GM = TR - TVC \quad (1)$$

where GM = gross margin; TR = total revenue (price × marketable quantity); TVC = total variable cost (i.e., costs which change as output changes).

2.2. Estimates of Costs and Benefits Associated with Cassava Production under Insecticide Control of Whitefly

The estimated costs included costs of equipment, labor and inputs (insecticide, water). The value of labor was captured as per activity/task completed by the farmer group and the cost per hectare of different operations specified. The cost of planting material (cuttings) was not considered because it does not vary with varieties and remains constant in all locations of the study. Indeed, they are considered as farmers' saved materials in East Africa [34,35] and they did not incur any cost at the time of the study. Fixed costs such as land, buildings (for storing equipment) or insurance were not included. Total costs that vary for each control method were calculated using the following formula, as stated by CIMMYT [36]:

$$C_i = \sum V_i \quad (2)$$

where V_i represents the costs that vary in Uganda shillings in period i, which includes labor, chemicals and the rental of a sprayer to apply the chemical among others.

The benefits were represented by the saving of cassava from whitefly damage, calculated as the market value of the roots. The yield corresponds to the part of the harvest that can be sold or used for self-consumption. The yield in this experiment was adjusted downwards by 20% to cater for differences in management (10%), plot size (5%) and harvest date (5%) [36]. The output price was the farm gate price as stated by the farmers. The impact of the output price on the profitability of insecticide use was analyzed through sensitivity analysis. The costs and benefits for the period of two seasons, 2019 and 2020, were calculated. The benefit–cost ratio (total benefits divided by total costs) was determined by comparing the costs incurred for chemical control with the financial benefits resulting from the control, i.e., the commercial value of plants that were saved from whitefly infestation. The resulting ratio expressed the efficiency of the treatment for the period considered.

Cost–benefit analysis not only based decisions on costs and benefits, but also examined the value of net benefits (NB), after deducting costs from benefits [37]. The net benefits were computed as the value of benefits gained minus the value of costs incurred. The formula in Equation (3) was employed to calculate the benefit–cost ratio (BCR), i.e., BCR = total cassava benefits/total production cost:

$$BCR_i = \frac{\sum B_i}{\sum C_i} \quad (3)$$

where B_i = the whitefly control alternative's benefit in year i, where i = 0 to n years (n = the total number of years for the whitefly control alternative's duration); C_i = the whitefly control alternative's costs in year i, where i = 0 to n years. Since the costs and benefits for the different treatments were largely constant over the study duration of two years, the benefit cost ratio was computed without discounting. Table 1 below:

Table 1. Interpretation of BCR.

BCR < 1.0	BCR = 1.0	BCR > 1.0
In economic terms, the costs exceed the benefits. Solely on this criterion, the whitefly control alternative should not be allowed to proceed.	Costs equal the benefits, which means the whitefly control alternative should be allowed to proceed, but with cautious support.	The benefits exceed the costs, and the whitefly control alternative should be allowed to proceed.

The calculated benefits and costs of a given whitefly control alternative vary depending on the input data applied in the cost–benefit analysis. The range of potential outcomes for differing inputs were gauged using a sensitivity analysis, to determine where the potential net benefits of whitefly control alternative would be negative.

2.3. Calculation of the Marginal Rates of Return for the Different Spray Regimes

The marginal rate of return was estimated as the amount of revenue per additional item, divided by the cost per additional item produced. In other words, it is the amount of additional revenue that a cassava farmer would expect to earn for each additional shilling that she/he spends on production. Using a marginal rate of return, a farm can determine whether, or not, the operations are profitable. According to CIMMYT [36] and Varian [38], the easiest way to describe feasible production plans is to list them: that is, listing all combinations of inputs and outputs that are technologically feasible. The set of all combinations of inputs and outputs that comprise a technologically feasible way to produce is called a production set.

Goto and Suzuki [39] and Nicholson and Snyder [40] proposed a Cobb–Douglas production function of the form in Equation (4):

$$f(x_1, x_2) = Q_i = \alpha x_1^a x_2^b \tag{4}$$

where Q_i is the quantity of cassava harvested from a given plot/spray option i, x_1 and x_2 are the inputs used in cassava whitefly control, the parameter α measures the scale of production (how much output would be obtained if one unit of each input was used). The parameters a and b measure how the amount of output responds to changes in the inputs x_1 and x_2, respectively. In log-linear models, Equation (5) becomes:

$$\ln q = \ln A + a \ln x_1 + b \ln x_2. \tag{5}$$

Coefficient A (originally α) represents the percent increase in Q_i (taking the log of its values) for a 1 unit increase in x_i (not log transformed):

$$\alpha = \frac{\Delta \ln(Q)}{\Delta x} \tag{6}$$

Hence, A is an estimate for the rate of return for an added input unit, $\alpha \approx MRR$. Thus, the marginal rate of returns was estimated as the increase in net benefits for each additional insecticide spray divided by the additional spray costs, i.e., $MRR = \frac{\text{increase in net benefits}}{\text{additional spray costs}} \times 100$.

To determine the most acceptable recommendation, the different insecticides application treatments were arranged in order of increasing costs. Comparisons were made between one alternative and the next in a stepwise manner. A value of marginal rate of return of less than one was an indication that the increase in cassava returns did not compensate for the additional cost of applying insecticide [21,36].

2.4. Cost Efficiency Analysis

To generate profit, resources are used to produce some level of output which could positively influence production cost. To examine this relationship, a stochastic frontier cost analysis [41,42] was performed on 18 farmer groups with about 200 farmers in total.

The cost function approach was preferred over the profit function approach to avoid problems of estimation that may arise in situations where farm households realize zero or negative profits at the prevailing market prices [41,43]. The model helps to account for the inefficiency component separately from measurement error and other statistical noise in the data. Accordingly, a stochastic cost function was constructed using a Cobb–Douglas function form (Equation (7))

$$\ln C = \beta_0 + \sum_{i=1}^{3} \beta_i \ln P_i + \beta_4 \ln Q + V_i + U_i \quad (7)$$

where:

C = minimum cost associated with cassava production

P_i = price of variable input (insecticide, personal protective equipment, labour to apply insecticide)

Q = cassava output measured in kg

β_i = vector of parameters

V_i = random variables such that Vi is normally distributed with a mean of 0 and variance σ^2_v.

U_i = non-negative random variables that account for cost inefficiency such that Ui are independently distributed with a mean μ variance σ^2_u.

3. Results and Discussion

3.1. Summary Statistics on Cassava Production

The average number of plants harvested per plot was 11, although NASE 12 had a higher number at 13 plants (Table 2). The higher number of plants for NASE 12 was attributed to the high germination percentage and good plant establishment. Generally, improved varieties produced more tubers than the landraces. The tuber yield per hectare was highest with NASE 12 at 83,802 tubers followed by NASE 3 at 70,272. The improved cassava varieties had more root weight compared to the landraces. The cassava yield (weight of roots) was greatly influenced by variety cultivated. NASE 12 had the highest marketable weight of 26,542 kg per hectare followed by the local variety with 24,632 kg and then NASE 3 at 24,492 kg. This is consistent with Manze et al. [44], who found that the top performers (in terms of high yield and disease resistance) were mostly the improved varieties released after 2011 while the worst performers were the local varieties. Given the high yielding and pest and disease resistance attributes of improved cassava varieties, there is a need to stimulate the demand for these varieties by relaxing the constraints farmers face when accessing agricultural knowledge and improved varieties.

Table 2. Cassava Production summaries by variety.

Variety	No. of Plants/Plot	Total Number of Tubers/ha	Total Tuber Weight (kg)/ha	Marketable Tuber Weight (kg)/ha	Farm Gate Price (UGX/kg)
LOCAL	11.61	61,542.58	29,128.42	24,632.13	323.57
MKUMBA	10.46	56,073.94	25,298.68	22,629.07	312.58
NASE 3	10.65	70,271.98	27,091.43	24,491.58	324.93
NASE 12	12.85	83,801.55	30,471.61	26,541.50	336.54
Average	11.39	67,922.51	27,997.54	24,573.57	324.40

Source: Field Data, 2020 and 2021.

Cassava farmers stated the farm gate prices per kilogram of NASE 12, NASE 3 and local to be higher than that of MKUMBA (Table 2). Generally, at the farm gate, a farmer expected to get about 324 shillings (Exchange rate: 1 USD = 3600 (average exchange rate for August 2020 to August 2021)) per kilogram of fresh cassava compared to about 576 shillings, if they travelled to the market. Although MKUMBA is resistant to whiteflies, CMD and CBSD [45], and has high dry matter content as well as excellent sensory attributes

for flour-based meal, it fetched a lower price than the local variety. This might be attributed to the fact that farmers' verdicts were based on raw and boiled root assessment with consideration of yield, taste, mealiness and fibrousness, where MKUMBA was rated poorly compared to other varieties. In contrast, NASE 12 fetched the highest price at the farm gate of 336 shillings per kilogram. This shows the need for breeding teams to collaborate with multidisciplinary teams to collect all relevant data to provide additional data points for breeding decisions.

Comparing average prices by location, farmers in Bugiri indicated that they received about 397 shillings per kilogram at the farm. These were followed by Pallisa and the least was Luwero (Table 3). This could be attributed to the fact that Bugiri, Pallisa and Serere are located in areas of high cassava production and consumption, which generated high demand and therefore better market prices compared to Luwero and Buikwe, where the crop is mainly for home consumption. Luwero had the lowest farm gate price perhaps because the main staple food in Luwero is cooked banana (popularly known as "matooke" in Uganda) and cassava is mainly used locally as snacks. Hence farmers produce and eat more banana than cassava given that the demand for fresh tubers locally is less. Indeed, cassava in Luwero is consumed wholly fresh, hence has a limited utilization base while, in Eastern Uganda, cassava is both for food security and a major source of income [46]. It has high demand both at a domestic level and regional level in Kenya in the form of chips and flour. With this wide utilization base, including industrial use, the price goes up compared to Luwero in Central Uganda that uses bananas as a major source of food and income. This is in line with Nakabonge et al. [46] who found that, in the Teso region (Eastern Uganda), farmers mostly grew improved cassava varieties which were essentially for commercial purposes, hence the high price.

Table 3. Average cassava farm gate prices by location.

District	Farm Gate Price (UGX/kg)
Bugiri	396.51
Buikwe	315.39
Kamuli	289.92
Luwero	234.34
Pallisa	360.97
Serere	349.30
Average	324.40

Source: Field Data, 2020 and 2021.

3.2. Costs and Benefits of Insecticide Application to Control Whiteflies in Cassava

With regards to the average costs per hectare, these varied across treatment regimes. For instance, the early protection (EP) costs were approximately 4.1 million shillings/ha followed by NEP at 3.91 million shillings/ha and DP was 3.89 million shillings/ha (Table 4). To ensure uniform results, analysis was carried out without the long protection (LP) treatment regime, since it was eliminated after season one.

NASE 12 registered the highest incomes per hectare of 9.2 million shillings/ha followed by the local variety at 8.3 million shillings/ha and the NASE 3 at 8.0 million shillings/ha due to the higher prices attached to them. However, by spray regime, NASE 12 and local varieties brought more income under the DP treatment, while NASE 3 and the MKUMBA brought more income under EP and NP treatments (Table 4). This implies that, while it is encouraged to use imidacloprid at the early stages of cassava growth on whitefly susceptible varieties so as to increase cassava yield (weight of roots) and hence result in higher incomes, it is not cost effective to apply insecticide for whitefly control on whitefly-resistant varieties. Overall, DP was the most worthwhile treatment because it resulted in the net revenue. This is in line with Avicor et al. [47] who stated that farmers should be encouraged regarding the judicious use of insecticides to control cassava whitefly with sustained monitoring of their resistance status to these insecticides.

Table 4. Cassava costs and revenue per hectare by treatment regime and variety ('000).

	Production Costs	Variety				Avearge	
		LOCAL	MKUMBA	NASE 12	NASE3		
Treatment Regime	**Cost (UGX/ha)**	**Income (UGX/ha)**	**Income (UGX/ha)**	**Income (UGX/ha)**	**Income (UGX/ha)**	**Revenue (UGX/ha)**	**Net Benefits (UGX/ha)**
DP	3894	11,100	8475	10,500	7976	9509	5615
EP	4095	8965	7585	9410	8897	8714	4620
NEP	3914	7157	5875	9552	6790	7343	3429
NP	2988	6000	8664	7210	8230	7526	4538
Average	3862	8306	7650	9163	7973	8273	4411

NB: DP/dipping = no spraying at all but the cuttings are dipped in chemical for some hours before planting, EP = dipping plus spraying once every 2 months up to 4 months after planting, NEP (no early protection) = no dipping and spraying starts at 5 months after planting for once every 2 months up to 7 months after planting and NP = no chemical application at all. Source: Field Data, 2020 and 2021. ('000) = figures are in thousands.

The farmers in Pallisa, Kamuli and Bugiri earned more income under DP (13.3, 10.3 and 8.4 million shillings/ha, respectively), in Luwero and Serere they earned more under EP (10.9 and 10.8 million shillings/ha, respectively) and in Buikwe they registered more income under NEP with 6.1 million shillings/ha (Appendix A, Table A1). An analysis of variance (ANOVA) test on tuber yield was conducted using a one-way ANOVA [48]. Bartlett's chi-squared statistic rejected the null hypothesis of equal means at the 1% level (Table 5).

Table 5. Analysis of variance (ANOVA) to compare means of treatment regimes ('000).

Source	**Sum of Square**	**Degrees of Freedom**	**Mean Square**	**F Statistic**	**Prob > F**
Between groups	7,039,500	3	2,346,500	9.05	0.000
Within groups	73,636,000	284	259,280		
Total	80,675,000	287	281,098		
Treatment Regime	**Mean Yield/Ha**	**Std. Deviation**			
DP	27.31	17.81			
EP	34.22	14.63			
NEP	29.88	16.73			
NP	20.58	15.03			
Average	28.00	16.77			

NB: DP/dipping = no spraying at all but the cuttings are dipped in chemical for some hours before planting, EP = dipping plus spraying once every 2 months up to 4 months after planting, NEP (no early protection) = no dipping and spraying starts at 5 months after planting for once every 2 months up to 7 months after planting and NP = no chemical application at all. Source: Field Data, 2020 and 2021. ('000) = figures are in thousands.

3.3. Gross Margins of Different Levels of Insecticide Application to Control Whiteflies

NASE 12 emerged as the most profitable variety, where a farmer has the potential to earn approximately 5.3 million shillings per hectare. This was followed by local and NASE 3 varieties, with gross margins of 4.4 and 4.1 million shillings per hectare, respectively. However, by insecticide application, the DP treatment regime gave high and positive gross margins across varieties including the local ones, followed by the EP treatment regime, while NEP exhibited the lowest profit except under NASE 12 and local varieties as shown in Table 6.

The cassava variety MKUMBA registered a gross margin of about 5.7 million shillings per hectare under no protection. This implies that for whitefly resistant varieties, it is not cost effective to apply insecticide for whitefly control. For the susceptible varieties, however, a judicious application of insecticide by dipping, or dipping and spraying once at two and four months of planting, would be sufficient. This is consistent with Legg et al. [49], who proposed the need to strengthen efforts to commercialize cassava crop through plant protection measures in order to have an increased yield and higher standards of crop.

Table 6. Gross margins (UGX/ha) by variety ('000).

Treatment Regime	LOCAL	MKUMBA	NASE 12	NASE 3	Average
DP	7206	4581	6606	4082	5615
EP	4870	3490	5315	4802	4619
NEP	3243	1961	5638	2876	3429
NP	3012	5676	4222	5242	4538
Average	4444	3788	5301	4111	4411

NB: DP/dipping = no spraying at all but the cuttings are dipped in chemical for some hours before planting, EP = dipping plus spraying once every 2 months up to 4 months after planting, NEP (no early protection) = no dipping and spraying starts at 5 months after planting for once every 2 months up to 7 months after planting and NP = no chemical application at all. Source: Field Data, 2020. ('000) = figures are in thousands.

On average, a farmer in Serere earned gross margins of about 5.9 million shillings per hectare while, in Luwero, the margins were 5.7 million shillings per hectare and 5.4, 3.9, 3.7 and 1.7 million shillings per hectare in Pallisa, Kamuli, Bugiri and Buikwe, respectively (Table 7). The DP and EP regimes still registered high margins per hectare across the districts and NEP exhibited the lowest gross margins except in Buikwe and Bugiri districts. This could be attributed to the low whitefly population and lower disease pressure at the time of the study in Buikwe and Bugiri districts, making it less economical to use insecticide in these areas.

Table 7. Gross margins (UGX/ha) by location ('000).

Treatment Regime	Bugiri	Buikwe	Kamuli	Luwero	Pallisa	Serere	Average
DP	4528	2063	6406	4594	9406	6706	5617
EP	2827	665	4112	6805	6505	6705	4603
NEP	4753	2204	1691	4500	2295	5132	3429
NP	3414	2535	4143	7512	4057	5601	4544
Average	3741	1727	3937	5711	5433	5917	4411

NB: DP/dipping = no spraying at all but the cuttings are dipped in chemical for some hours before planting, EP = dipping plus spraying once every 2 months up to 4 months after planting, NEP (No early protection) = no dipping and spraying starts at 5 months after planting for once every 2 months up to 7 months after planting and NP = no chemical application at all. Source: Field Data, 2020 and 2021. ('000) = figures are in thousands.

Running gross margin scenarios for the two best performing improved varieties, i.e., NASE 12 and NASE 3, we generated scenarios based on changes in prices and gross margins. Economic theory indicates that, if all things remain constant (*ceteris Paribas*), a change in price brings about a change in variable costs as well. Hence, as we varied prices/revenues, variable costs also varied. Under the DP treatment regime, NASE 12 was the most profitable when the price hypothetically increased by 25% and costs reduced by 25% leading to a gross margin of 5.2 as indicated in Table 8.

Table 8. Gross margin scenarios (UGX/ha) for NASE 12 variety ('000).

Price Increase %	Variable Cost Reduction %	Treatment Regime 1	Gross Margin 1 (UGX)	Treatment Regime 2	Gross Margin 2 (UGX)
10%	10%	DP	2050	EP	1931
15%	15%	DP	3175	EP	2802
20%	20%	DP	4200	EP	3772
25%	25%	DP	5225	EP	4743

NB: DP/dipping = no spraying at all but the cuttings are dipped in chemical for some hours before planting, EP = dipping plus spraying once every 2 months up to 4 months after planting. Source: Field Data, 2020 and 2021. ('000) = figures are in thousands.

NASE 3 was the most profitable when the price changed by 25% and costs changed by 25% leading to a gross margin of about 3.9 and 4.4 million shillings per hectare under the DP and EP treatment regimes, respectively (Table 9).

Table 9. Gross margin scenarios (UGX/ha) for NASE 3 variety ('000).

Price Increase %	Variable Cost Reduction %	Treatment Regime 1	Gross Margin 1 (UGX)	Treatment Regime 2	Gross Margin 2
10%	10%	DP	1596	EP	1780
15%	15%	DP	2392	EP	2638
20%	20%	DP	3190	EP	3582
25%	25%	DP	3988	EP	4427

NB: DP/dipping = no spraying at all but the cuttings are dipped in chemical for some hours before planting, EP = dipping plus spraying once every 2 months up to 4 months after planting. Source: Field Data, 2020 and 2021 ('000) = figures are in thousands.

A sensitivity analysis revealed that NASE 12 and NASE 3 gross margins were more sensitive to price changes of 20% and 25% as shown in Table 10. Though at these price levels incomes would significantly increase, the high increase in costs would be prohibitive for farmers, hence the 10% and 15% price change would be more favorable. This is in line CIMMYT [36], which states that whether farmers market little or most of their produce, they are interested in the economic return. Farmers will always consider the costs and risks of changing from one practice to another and the economic benefits resulting from that change. Researchers, therefore, should be clear about the benefits, costs and risks associated with a particular technology for farmers to make rational decisions.

Table 10. Sensitivity analysis of gross margins to price and variable cost changes for NASE 12 and NASE 3.

Price Increase %.	Variable Cost Reduction%	Gross Margin Sensitivity Price Changes
10	10	0.18
15	15	0.26
20	20	0.33
25	25	0.40

Source: Field Data, 2020 and 2021.

3.4. Calculated Benefit–Cost Ratios (BCR) and Analysis of Variance for the Different Treatment Regimes

While all insecticide application regimes had their BCRs above one, DP, EP and NP treatment regimes were above the minimum acceptable BCR of 1.5 (Table 11). However, it is important to note that simply following a rule that a BCR above one indicates success, and that a BCR below one would mean a failure or a rejection decision, can be misleading and may lead to a misfit with the intervention in which heavy investment is made. Hence, the BCR should be used as a conjunctive tool with different types of analysis such as the use of marginal rate of return (MRR) and other qualitative factors to make a good decision [30]. Similarly, Otte et al. [50] observed that a cost–benefit analysis is expected to indicate the management option with the greatest net benefits, but it does not by itself determine the best management choice.

Table 11. Cassava production costs and yields of different insecticide application treatments.

Item	Treatment Regime ('000)			
	DP	EP	NEP	NP
Bush clearing	173	173	173	173
Ploughing	296	296	296	296
Planting	296	296	296	296
Weeding	1482	1482	1482	1482
Dipping + Spraying labor	108	276	128	
Harvesting labor	741	741	741	741

Table 11. *Cont.*

Item	Treatment Regime ('000)			
	DP	**EP**	**NEP**	**NP**
Insecticides				
Imidaclopid (Confidor)	35	68	35	
Equipment				
Gumboots	80	80	80	80
Overcoats	180	180	180	
Goggles	40	40	40	
Gloves	40	40	40	
Jerricans	28	28	28	
Drum	80	80	80	
Knapsack sprayers	160	160	160	
Nose masks	24	24	24	
Basins	32	32	32	
Soap	99	99	99	
Total Cost_ha	3894	4095	3914	3068
Marketable Yield_ha (kg)	26	26	22	23
Adjusted Market Yield_ha (kg) (20%)	21	21	18	19
Farm Gate Price (UGX)	0.354	0.321	0.310	0.313
Gross Benefits_ha (UGX)	7365	6777	5562	5870
NET BENEFITS_Ha (UGX)	3471	2683	1648	2802
BCR = Gross Benefits/Total Cost	1.9	1.7	1.4	1.9

NB: DP/dipping = no spraying at all but the cuttings are dipped in chemical for some hours before planting, EP = dipping plus spraying once every 2 months up to 4 months after planting, NEP (no early protection) = no dipping and spraying starts at 5 months after planting for once every 2 months up to 7 months after planting and NP = no chemical application at all. Source: Field Data, 2020 and 2021.

3.5. Marginal Rates of Return for the Different Spray Regimes

Overall, the marginal rate of return on moving from NP to DP was 1.66 (166%) and it was above 100% which is the minimum acceptable rate of return [36], as shown in Table 12. The yields of treatment regime EP were higher than those of treatment regime NP, but the value of the increase in yield was not enough to compensate for the increase in costs. Therefore, DP was certainly the most worthwhile alternative to the farmers' practice of no protection. Treatment regimes EP and NEP had higher costs but fewer net benefits than NP, hence EP and NEP were dominated treatment regimes [32]. The DP treatment regime registered the highest yield and its costs provided an acceptable rate of return. The regime is less costly in terms of the quantity of chemicals and other associated expenses. Since cassava is protected during the critical growth period of 1–2 months after planting [51], there is less disease incidence and less farmer exposure to chemical contact. Furthermore, applying chemicals to cassava cuttings at planting saves on time spent on insecticide spraying activities. Thus, while all treatment regimes registered positive net benefits, these were highest for the DP treatment. Therefore, the judicious application of systemic insecticide at planting provided the most cost effective control of whitefly problems in cassava production and improved root yield hence resulted in higher returns. This suggests that, for farmers to maximize their cassava returns, they should not apply insecticide beyond dipping.

Table 12. Marginal rate of returns for the lowest cost treatment regime.

Treatment	Total Costs That Vary (Shs/ha) ('000)	Net Benefits (Shs/ha) ('000)	Marginal Rate of Return
NP	3068	2802	-
DP	3894	3471	1.66 (166%)
NEP	3914	1648	−91.15 (−9115%)
EP	4095	2683	−3.93 (−393%)

NB: DP/dipping = no spraying at all but the cuttings are dipped in chemical for some hours before planting, EP = dipping plus spraying once every 2 months up to 4 months after planting, NEP (no early protection) = no dipping and spraying starts at 5 months after planting for once every 2 months up to 7 months after planting and NP = no chemical application at all. Source: Field Data, 2020 and 2021. ('000) = figures are in thousands.

3.6. Estimated Cost Function

The results obtained through marginal analysis confirmed that the judicious use of insecticides at the planting of cassava was the most cost effective treatment as it yielded more returns on investment. Further analysis was performed to determine whether resources were being used efficiently (cost minimization) given the current level of output. The estimates of the stochastic frontier cost function are as indicated in Table 13. The coefficient of chemical application price had a significant and positive relationship with the cost of cassava production. This implies that chemicals were a significant cost in cassava production in the study area. This suggests that any policy to increase cassava production must lower the prices of associated insecticides. The result is consistent with Akongo et al. [52]. Additionally, the coefficient of personal protective equipment (PPE) price had a significant and positive relationship with the cost of cassava production. This implies that personal protective equipment is a significant direct determinant of the total cost of cassava production. This suggests that to support cassava insecticide users, there is a need to reduce the cost of the personal protective equipment that they use. Furthermore, the coefficient on cassava output (yield) was found to have a direct relationship with the cost of cassava production, though it was not significant. This implies that cassava output directly influences the total cost of cassava production. However, in order for cassava producers to make a profit, they need a higher output. Thus, fewer chemicals and higher yielding varieties should be used to produce more tons of cassava, hence reducing the chemical and labor costs needed in production. This also has environmental benefits since producing more cassava with less insecticide use also means less pollution to the environment. Thus, higher output calls for the need to judiciously use insecticides and higher yielding improved cassava varieties to produce more output per unit area, hence compensating for the costs incurred. The input variable of the labor needed to apply chemicals was positive but not significant in the model. This suggests that once the farmer has the chemical and personal protective equipment, the labor needed to apply chemicals should not be a constraining factor. The gamma value of 0.983 ($\gamma = 0.983$) is quite high, indicating the goodness of fit and that the assumptions of the error terms distribution were correctly specified. The gamma value of 0.983 implies that 98.3% of the random variation in the model was due to economic inefficiency. The mean economic efficiency was 0.98 implying that the inefficiency from the frontier model was only 2%.

Table 13. Stochastic cost frontier for cassava production.

Stoc. Frontier	Normal/Truncated-Normal Model	Number of Obs = 178
Log likelihood	405.84142	Wald chi2(4) = 2535.04
Variable		Prob > chi2 = 0.000
lnTotalCOST_ha	**Coefficient**	**Standard Error**
Chemical price	1.4×10^{-6} ***	2.6×10^{-7}
PPE price	4.6×10^{-7} ***	2.7×10^{-8}

Table 13. *Cont.*

Stoc. Frontier	Normal/Truncated-Normal Model	Number of Obs = 178
Labor on chemical use price	3.9×10^{-7}	3.5×10^{-7}
lnOutput_ha	1.3×10^{-4}	1.4×10^{-3}
Constant	1.5×10 ***	1.4×10^{-2}
sigma2	$6. \times 10^{-3}$	2.1×10^{-3}
gamma	9.8×10^{-1}	
sigma_u2	5.9×10^{-3}	
sigma_v2	9.9×10^{-5}	

***: Significant at 1% level, ln = log transformation. Source: Field Data, 2020 and 2021.

4. Conclusions and Recommendations

The purpose of the study was to determine the most cost effective insecticide application regime to control cassava whiteflies. The costs involved were the purchased inputs (chemicals and water), the labor to apply the chemicals and labor to haul water for mixing with the chemicals. The benefits were the sales of cassava roots at maturity. NASE 12 and local varieties registered higher gross margins under the DP regime, while NASE 3 and MKUMBA exhibited higher gross margins under EP and NP regimes, respectively. While all insecticide application regimes had their BCRs above one, DP registered a MRR above 100% indicating that it was the most worthwhile option. We conclude, therefore, that it is not cost effective to apply insecticide to control whiteflies other than by dipping.

The findings from this study indicate that high yield and disease resistance are key in assessing the profitability of a cassava variety, hence its adoption by farmers. Dipping is crucial to protect cassava during the early stages of establishment because, if the plant establishes well, then tuber formation is also good hence higher yields and profits yet with no subsequent spraying costs. MKUMBA, a whitefly-resistant variety, registered the highest gross margin under no protection. This implies that, for whitefly-resistant varieties, it is not efficient to apply insecticide to control whiteflies. Nonetheless, in pest management, it is usually good practice to use several control technologies against a pest (resistant varieties and insecticide), so as to reduce the risk of one of them failing to work. The study also revealed that, while insecticide users incurred more production costs, they also registered higher yield and hence more profit than non-insecticide users, especially if the insecticide was applied at the early stages of cassava growth. The marginal rate of return increased as one moved from no protection to a dipping regime, but reduced from dipping to other treatment regimes. This implies that dipping is sufficient to protect cassava from critical whitefly damage and hence the most cost-effective treatment regime.

The costs of chemicals and personal protective equipment were the major costs incurred by those who applied insecticide. Consequently, any measures taken towards reducing the cost of chemicals will increase the profitability of cassava production. The mean cost efficiency of cassava production was 0.98, implying that there are limited opportunities to increase profit through increased efficiency in resource utilization. This suggests the need for technological improvement, for instance, by adopting higher-cassava-yielding varieties, which would raise the profit margins for farmers. Therefore, there is a need to encourage farmers to work in groups in order to enable them access credit to procure farm inputs. In addition, there is a need to strengthen efforts to commercialize cassava crop through plant protection measures in order to have increased yield and higher standards of the crop.

Author Contributions: I.B.: Conceptualization, methodology, formal analysis, investigation, data curation, writing original draft; C.A.O.: conceptualization, funding acquisition, investigation, methodology, project administration, resources, supervision, validation, writing—review and editing; A.B.: methodology, validation, formal analysis, writing—review and editing; J.C.: resources, validation, writing—review and editing; A.O.: validation, writing—review and editing; J.M.: validation, writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Bill and Melinda Gates Foundation through the University of Greenwich grant number INV-010435 and previously OPP1200124. The authors are grateful to the Bill and Melinda Gates Foundation (BMGF) for funding this research through the African Cassava Whitefly Project Phase two (ACWPII).

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Data that support findings of this study are available upon request through the corresponding author.

Acknowledgments: Under the grant conditions of the Foundation, a Creative Commons Attribution 4.0 Generic License has already been assigned to the author-accepted manuscript version that might arise from this submission. We thank the farmers of Kamuli, Pallisa, Luwero, Buikwe, Bugiri and Serere districts who participated in this study. Thanks, also, to the field research assistants and technicians who captured the required data from all on-farm trials.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Costs and revenues by spray regime and district ('000).

	All Districts	Bugiri	Buikwe	Kamuli	Luwero	Pallisa	Serere
Treatment Regime	Cost (UGX/ha)	Income (UGX/ha)	Income (UGX/ha)	Income (UGX/ha)	Income (UGX/ha)	Income (UGX/ha)	Income (UGX/ha)
DP	3894	8422	5957	10,300	8488	13,300	10,600
EP	4095	6922	4760	8207	10,900	10,600	10,800
NEP	3914	8667	6118	5605	8414	6209	9046
NP	2988	6402	5523	7131	10,500	7045	8589
Average	3862	7603	5589	7799	9573	9295	9779

('000) = figures are in thousands.

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Research on Consumer Perception Regarding Wine Products and Wine Tourism in the Republic of Moldova

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Abstract: Traditions of vine cultivation and wine production have been formed in Moldova over centuries. According to folk traditions, wine is an integral part of any event organized by the locals. Wine tourism is a particularly significant sector for the country's economy. Although it only emerged at the end of the 20th century, it is growing in importance every year. To contribute to this area of scientific discourse, a study on consumers' perception of wine products and wine tourism in the Republic of Moldova was conducted. The main respondents who participated in the survey were citizens of the country, but respondents from Romania and Ukraine also participated. The results obtained indicate that wine products are consumed by the majority of the respondents participating in the survey and that wine tourism has continuity in its development and is of clear interest among citizens. The diversity of the tourist offers of the wineries and the recreational areas in which they are located are of course of particular importance when selecting a wine tour.

Keywords: respondents; questionnaire; consumers; visitors; wine product; wine tourism

Citation: Guțan, V.; Șavga, L.; Zugravu, C.L.; Bucur, D.; Zugravu, G.A. Research on Consumer Perception Regarding Wine Products and Wine Tourism in the Republic of Moldova. *Agriculture* **2023**, *13*, 729. https://doi.org/10.3390/agriculture13030729

Academic Editors: Hung-Hao Chang, Pei-An Liao and Jiun-Hao Wang

Received: 6 March 2023
Revised: 18 March 2023
Accepted: 20 March 2023
Published: 22 March 2023

1. Introduction

The world of wine is divided into two large world areas: the "Old World" with France, Italy, Spain, Germany, followed by Austria, Hungary, Slovenia, Croatia, Greece and the "New World" with Canada, the United States, Chile, Argentina, South Africa, Australia and New Zealand [1–3]. The successful model and trend of food and wine tourism adopted above all from the United States is nothing more than the result of inspiration from the European heritage with the attempt to reproduce the same atmosphere as in Les Routes des Vins of Bordeaux, the domains of Burgundy, and the wine and flavor routes of Italy [4,5]. Rural areas cover most of Europe's surface. The urban-rural relationship has always been a characteristic feature of the European area leading to a permanent profitable exchange of goods, people, resources, knowledge and lifestyles. Although in the second half of the 20th century this relationship temporarily entered a crisis, there is no doubt that the rural natural—human landscape represents a factor of strong territorial identity and a resource of primary importance, both for local communities and for the community. Moreover, wine tourism represents one of the levers to tie the threads of the dialogue between the city and the countryside. The wine from the territories where it is produced is the pivot around which revolve a multiplicity of consumption activities. These generate income, jobs, economic and, consequently, social value. It should be noted in this respect that 50% of Italian wine production still belongs to a specific place. In recent decades, however, micro-enterprises have decreased. In 2015, there were 34,166 companies that produced less than 100 hL, representing 74% of the total [6–8].

One of the main interests of the citizens of modern society is the organization of their free time. In order to cover this demand with an incredible speed and a remarkable continuity of growth, the tourism industry has developed in the last century, both worldwide

and in the Republic of Moldova [9–11]. Tourism has proven to be a very important activity for the economy of our country. Tourism in the Republic of Moldova has a rather large potential for development, presenting a complex combination of natural environments (natural areas, massive forests in the center of the country, rocks, valleys, meadows) and man-made ones (medieval settlements, fortresses, cities with various architectural styles, spas, festivals, wineries, etc.) [12–15].

Our research into consumer perception regarding wine products and wine tourism is concentrated on representative wineries from the Republic of Moldova (Figure 1).

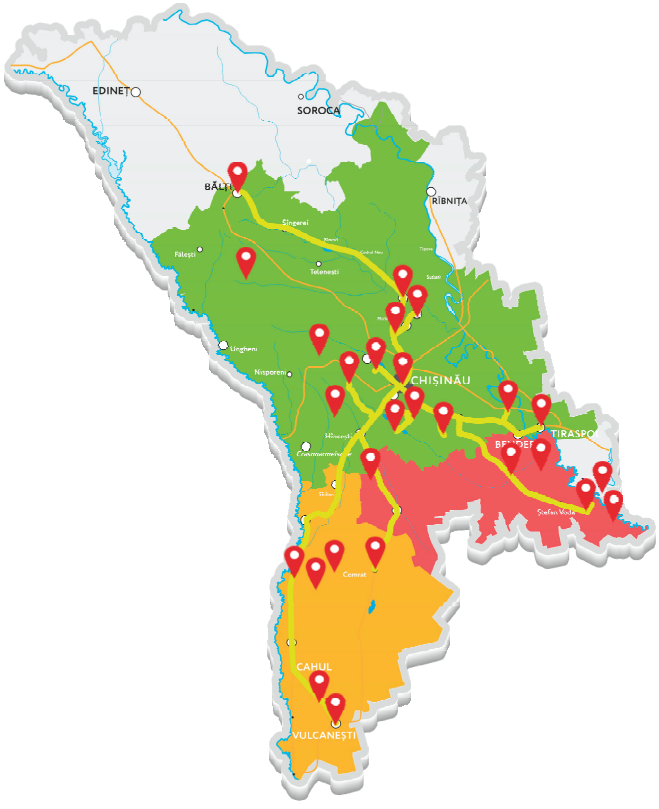

Figure 1. Map of wineries in Republic of Moldova. Sources: https://wineofmoldova.com/en/ (accessed on 16 March 2023).

Among citizens there is a growing demand for short-term vacations, weekend vacations, and individualized tourism. Today's tourists show a growing interest in tranquility, direct contact with nature, culture and avoiding crowds [16–18]. At the same time, tourists advocate for relaxing tourist visits that stimulate them mentally and physically. In our opinion, wine tourism could satisfy the stated requirements. It is considered to be one of the forms of tourism of the Republic of Moldova which, through its potential, could easily compete on the international market [19–21].

The purpose of this research is to analyze consumers' perception of wine products and wine tourism, which can thus support the foundation of a wine tourism development strategy in the Republic of Moldova, starting from the identification and validation of the factors, expressed in hypotheses, which can stimulate the consumption of wine products.

Starting from the concepts found in the literature with the help of the bibliometric study carried out using VOSviewer software, we created a questionnaire to investigate the perception of consumers of wine products and wine tourism in the Republic of Moldova.

At the same time, with the help of the questionnaire, we also analyzed the importance of the main factors that can contribute to the development of the wine sector in the Republic of Moldova. In this sense, with the help of a fuzzy application developed in Matlab, we have developed a qualitative fuzzy analysis methodology. We thus managed to identify the importance of the factors that can stimulate the development of this tourism sector in the Republic of Moldova.

2. Literature Review

The art of winemaking has been valued by the population of the country since ancient times. In the country's aquatic spa treatment centers, grapes and grape juice are widely consumed [22,23]. Wine-related tourism offers a variety of guided tours in wine cellars, in underground cities with streets named after grape varieties, in underground galleries, in primary wine processing enterprises, in the production of sparkling wine, divine balsams, in wine cellars, in bottling rooms, rooms with a variety of themes, wine tasting rooms, banquet rooms, conference rooms, in wine shops, etc. [15,24,25]. Winery visitors, in addition to the basic program of guided tours and tastings, could also benefit from other services. These include: custom wine orders, tours of vineyards and other nearby attractions, bike tours, picnic areas, hotel services, terraces, children's playgrounds, museums, art galleries, fishing, hunting, swimming pools, saunas, culinary master-classes, etc. [26–30]. During the season, tourists can participate in the wine production process. Most wine companies offer the possibility of organized tours for visitors [31–36]. Here tourists can gain experience and learn about the complex production process, be present at the bottling process and, of course, taste the final product [37–40].

At a higher level are the generic wines with the possibility of indicating vintage and/or variety but lacking indications of origin; these can be produced with grapes from various areas and/or from various EU Member States. In contrast, the Protected Geographical Indication based on the name of a region or a specific place serves to designate a wine—originating in that region or place of a certain quality, reputation or other characteristic which may be attributed to the geographical origin. At least 85% of the grapes from which a PGI wine is obtained must come from that grape's geographical area [41–43].

In Moldova there are tourist routes "Wine Road in the Republic of Moldova" and "Wine Road of Moldova", which represent a substantial reason to visit the Republic of Moldova [44–48].

In recent years, thanks to the investments of the winery owners, and the support through grants and assistance of the Moldova Competitiveness Project, financed by USAID and the Government of Sweden, the number of wineries open to tourists has doubled [49].

3. Methodology

In order to investigate the stated theme, the authors used a series of research methods: exposition, systematization, questionnaire investigation, induction and deduction, comparison, quantitative and qualitative analysis, synthesis. The questionnaire survey is a method of questioning social facts (opinions, attitudes, motivations, etc.) at the level of human groups, smaller or larger, and of analyzing quantifiable data in order to describe and explain them [50–52]. The survey is a fast and efficient method of describing opinions. On the other hand, esearch studies also make use of complementary methods (observation, analysis, documentation) [53–57]. The survey on consumer perception of wine products and wine tourism in the Republic of Moldova was conducted online on Google forms, mainly among the citizens of the Republic of Moldova, using a sample of approximately 110 people. A total of 200 questionnaires were distributed in 32 counties and 134 were returned. After checking the validity of the returned questionnaires, 24 questionnaires that were incomplete or had logical mistakes were deleted, meaning that 110 valid questionnaires were obtained; the effective response rate was 55%.

The sample for this population was drawn randomly by the RDD method (random digit dialing) and was achieved by calculating the weights depending on the region and the environment of residence and gender.

Given that representativeness depends on the sample generated by means of statistical tools, eventually, there may be no exact relationship between the concepts of representativeness and coverage, since the latter is the proportion of elements selected in the sample with respect to the population.

The research results allowed making some remarks and drawing some conclusions regarding consumer perception of wine products and the development of wine tourism.

The research results presented here were derived using the graphic and numerical methods. The graphical method is used to visually identify the trends in the data. The following types of graphs were used in the present work: bar graph, line graph, pie graph and diagram. The numerical data are more objective and accurate. Since they complement each other, it is good to use these methods in combination.

The synthesis and deduction methods were used to formulate conclusions and argue for some recommendations.

Furthermore, through inductive reasoning, data collected during semi-structured interviews are linked to relevant theories gathered during the systematic literature review using VOSViewer 1.6.19 software.

The first objective of this study was to carry out a bibliometric study of wine tourism products. The research of the database of ISI indexed articles, related to the traditional products, was done for ten years (2012–2022) on the trends regarding the traditional product concept. The literature was extracted and analyzed using the Web of Science database. VOSViewer software was used to identify and visualize key trends, influential authors and journals.

Furthermore, 340 WOS articles from 2019 to 2023 were selected for detailed study based on three main criteria:

- Topics regarding the wine products and wine tourism,
- Document type "article"
- Year of publication in the period 2019–2023.

We performed several types of analyses regarding wine and wine tourism products; we analyzed the period 2019–2023 in its entirety, after which we analyzed the most cited articles and the most recently accessed articles. Extracting information from the Web of Science Database and VOSViewer software were the main techniques for analysis and reporting. Research themes were extracted and analyzed to identify and visualize main trends, (influential) authors and related journals.

VOSviewer provides visualizations of bibliometric networks. VOSviewer therefore displays only the nodes in a bibliometric network and does not display edges between nodes. In the visualizations provided by VOSviewer, the distance between two nodes roughly indicates the relationship between the nodes. By providing distance-based rather than graph-based visualizations, VOSviewer is particularly suitable for viewing larger networks. Because of its strong focus on visualization, VOSviewer offers less functionality for bibliometric network analysis than other tools. However, VOSviewer has some special text extraction features.

We applied VOSviewer to data obtained from the Web of Science database as early as 2019 to ensure that only hot topics are included to detect trends in wine tourism. We did not focus only on the top journals in this field, but used a keyword approach applied regardless of the source of the paper. Thus, brand management has been investigated using inclusion criteria based on thematic keywords found in more than twelve sources. Based on this, grouping could be developed. There are six major keyword clusters related to wine tourism in the most cited WOS articles from 2019–2023 (Figure 2), which we determined based on thematic clusters as:

- "wine tourism";
- "strategy";

- "rural tourism";
- "regions";
- "dimensions";
- "wine routes".

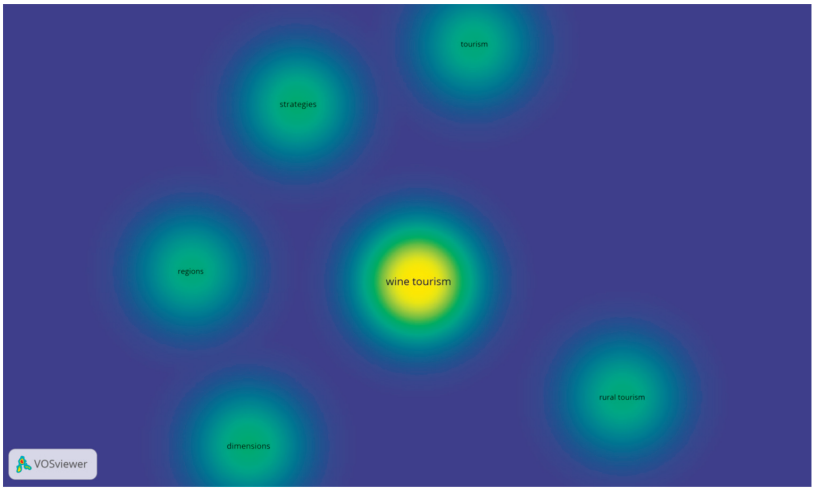

Figure 2. Major keyword clusters related to wine tourism in the most cited WOS articles from 2019–2023.

In this scientific investigation the authors present the results of a social survey. It was carried out in order to discover the preferences of different wine consumers and elucidate the interest of the population that participated in the survey regarding the visit to wineries in the Republic of Moldova and the degree of satisfaction received as a result of these visits [50,58–60]. The exposed results can be seen in Figure 3.

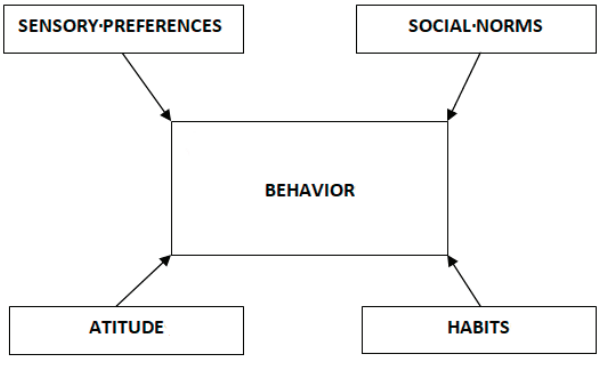

Figure 3. The design of research hypotheses for a social survey of wine tourism consumers.

Based on the conceptual model, the following research hypotheses were established:

Hypothesis 1. *There is a significant relationship between consumer attitude and intention to purchase wine tourism products.*

Hypothesis 2. *There is a significant relationship between social norms and the consumer's intention to purchase wine tourism products.*

Hypothesis 3. *There is a significant relationship between consumer habits and consumer intention to purchase wine tourism products.*

Hypothesis 4. *There is a significant relationship between sensory preferences and consumer intention to purchase wine tourism products.*

These research hypotheses on the factors that influence the behavior of consumers of wine products were verified with the help of the questionnaire, as described below.

4. Results

The survey on consumer perception of wine products and wine tourism in the Republic of Moldova included 20 questions. The first 5 questions of the survey included general data on the participants. These included: citizenship, place of birth, gender, age, and highest level of education of survey respondents. Questions 6–13 of the survey include data on consumption of wine products, their characteristics, disclosure of product information, reason for consumption, frequency of consumption, etc. Survey topics 14–20 include questions regarding visits to wineries and respondents' impressions of the results of these trips.

According to the data collected from the survey, citizens of the Republic of Moldova participated in the proportion of 96.3%, while Romanian citizens and citizens of other states have an equal share in the proportion of 1.8%. They are mainly from the academic community, but also from different branches of the national economy. Of the total number of respondents, 50.9% were born in rural areas and respectively 49.1% were born in urban areas. Respondents were 85.3% women and 14.7% men.

The age of the respondents who took part in the survey varied widely and can be seen in Table 1. The analysis of consumer perception used as segmentation criteria: age, gender and education according to Table 1.

Table 1. Distribution of respondents by age.

Demographic Variables	Categories	Subjects No.	Percent %
Gender	Male	16	14.70
	Female	94	85.30
Age	18–20	11	10.1
	21–30	22	20.2
	31–40	16	14.6
	41–50	33	30.3
	51–60	17	15.6
	>60	10	9.2
Place of birth	Rural	56	50.9
	Urban	54	49.1

Table 1 shows the proportion of respondents who participated in the survey according to their age. From the graph data, we notice that respondents of different ages took part in the survey: young, middle-aged and elderly people. Out of 110 responses regarding age, the majority of respondents, 33 people or 30.3%, are aged 41–50, followed by respondents aged 21–30 in second place (22 people or 20.2%); in 3rd place are the respondents aged 51–60 with a share of 15.6% (17 people), closely followed by those aged 31–40 years with a share of 14.6% (16 people). Finally, in the last place, we find the respondents who have reached the age of 18–20 years with a share of 10.1% (11 persons) and those aged over 60 years with a share of 9.2% or 10 persons.

We conclude that the participation of different age groups in the survey will allow expressing the most truthful answers to the questions in the questionnaire.

When asked about the last level of education, we establish that respondents with university studies reach a share of 45.9%, those with postgraduate studies (master's, doctorate, etc.) reach a share of 36.7%, those with high school and post-secondary studies

reach a share of 7.3% each, and respondents without high school studies reach a share of 2.8%. Thus, the majority of respondents in the proportion of 82.6% are respondents with university and post-university education.

The investigation of the number of people who consume wine products showed that 60.9% of the respondents are regular consumers of these products, 30.9% consume wine products sometimes or rarely and 8.2% do not consume or are not interested in consuming these products. Therefore, out of the total number of respondents surveyed, 91.8% are consumers of wine products.

The next research question generated multiple responses regarding the sources/channels of information about wine products that are most accessible to the respondents. A total of 112 responses were obtained with the following results: media (television, press, etc.) 30.4% (34 people); internet 32.1% (36 people); store shelves 38.4% (43 people); specialized stores 36.6% (41 people); national days, festivals, exhibitions 40.2% (45 people); friends/colleagues 36.6% (41 people); other sources 5.4% (6 people). Thus, we observe that all usual sources of information more or less promote the consumption of wine products.

Multiple responses were also found to the question concerning the place where wine products are more often available to consumers for purchase. Consequently, the following results were obtained concerning the source of wine products: from own household 29.9% (23 persons); from specialized shops 50.9% (56 persons); directly from the factory 9.1% (10 persons); from supermarkets, markets, small shops 51.8% (57 persons); from fairs organized for special occasions 27.3% (30 persons); from festivals 16.4% (18 persons); from exhibitions 25.5% (28 persons); from tourist reception structures with public catering functions 2.7% (3 persons); from other places 3.6% (4 persons). Thus, wine consumers most often purchase wine products from specialized shops and markets.

Another research question concerned the reason for the choice of a wine product made by the winemakers of the Republic of Moldova. The ratings of the motives were: very important, important, indifferent, less important, slightly important. Thus, the motive of patriotism was rated as very important by 22%, important by 42%, indifferent by 8%, less important by 6% and slightly important by 8%. The motive of habit passed on by parents and grandparents was rated as very important by 6%, important by 31%, indifferent by 21%, less important by 7%, and slightly important by 9%. The motive of recently acquired habit was rated as very important by 5%, important by 43%, indifferent by 15%, less important by 11%, and slightly important by 2%. The motive of another person's suggestion was rated as very important by 10%, important by 47%, indifferent by 12%, less important by 6%, and slightly important by 6%. The motive of mere curiosity was rated as very important by 9%, important by 23%, indifferent by 28%, less important by 4%, and slightly important by 7%. The motive of promotion via different channels was rated as very important by 47%, important by 26%, indifferent by 6%, less important by 1%, and slightly important by 1%. The motive of food safety was rated as very important by 61%, important by 18%, indifferent by 4%, and slightly important by 2%. The motive of product characteristics (appearance, exterior, color, smell, taste, etc.) was rated as very important by 52%, important 27%, indifferent 7%, less important 1% and slightly important 3%. The curative motive (beneficial to health in small amounts) was rated as very important by 36%, important by 42%, indifferent by 9%, less important by 1%, and slightly important by 2%.

Thus, most of the motives presented in the questionnaire were rated as very important and important.

To analyze the working hypotheses, we processed the answers obtained with the help of the online questionnaire by means of a fuzzy analysis model of the hypotheses that influence the behavior of consumers of wine tourism products. For this purpose, we used the set of tools offered by Matlab R2020b.

Thus, for the analysis of the 4 hypotheses (sensory preference, social norms, attitudes, habits) we calculated an index regarding the importance of each of the working hypotheses in the manifestation of consumption behavior. Based on the data provided by the respondents, we converted the linguistic qualitative assessments (unsatisfactory, satisfactory,

average, good, excellent) into a vector of 3 numerical values (fuzzy triplet), because we used a triangular membership function.

This set of three numerical values (fuzzy triplet) is used to reflect the relative importance of the working assumptions.

$$IH1 = CA/Qt \quad (1)$$

$$IH2 = CSN/Qt \quad (2)$$

$$IH3 = CH/Qt \quad (3)$$

$$IH4 = CSP/Qt \quad (4)$$

where:

CA—the set of three numerical values of the attitude belonging to three of the 5 linguistic terms of the quality assessment scale,
CSN—the set of three numerical values of social norms belonging to three of the 5 linguistic terms of the quality assessment scale,
CH—the set of three numerical values of habits belonging to three of the 5 linguistic terms of the quality assessment scale,
CSP—the set of three numerical values of the sensory preferences aspect belonging to three of the 5 linguistic terms of the quality assessment scale.

For the defuzzification of global indices of sensory quality, we used a function created in Matlab called df.m

%defuzzificare

function Y = df(A)

$$Y = (3 \times A(1) - A(2) + A(3))/3$$

To order the importance indices of each hypothesis (obtained after defuzzification) and to determine the position within this comparative analysis, the following relationships are used in Matlab (according to expressions (1)–(4), and Tables 2–5):

CS = [df(IH1) df(IH2) df(IH3) df(IH4)];

[CSd, Ld] = sortrows(CS', −1);

[La, L] = sortrows(Ld);

Table 2. The importance weight ofe each hypothesis.

Hypotheses	Unimportant	Little Importance	Important	Very Important	Extremely Important
H1	0	0	33	44	33
H2	0	0	18	59	33
H3	0	0	22	55	33
H4	0	0	33	44	33

The 10th research question determined what kind of wine products are consumed by the interviewed respondents. Thus, 86% of the respondents prefer to consume moderately alcoholic beverages (wines, sparkling wines), and 14% of the respondents prefer to consume strong spirits (vodka, brandy, cognac, whiskey, liqueur, etc.). Thus, the majority of respondents prefer moderately alcoholic drinks.

On the basis of the 11th research question, the type of wine product consumed predominantly by the surveyed consumers was determined. Thus, 50% of the respondents consume wine, 30.9% consume sparkling wine, 12.7% consume vodka, brandy, cognac, whiskey, 2.5% consume liquor and 4% other beverages.

Table 3. Calculation of the triplets associated with the weight of the importance of each hypothesis.

Hypotheses	Calculation of the Set of Numerical Values Associated with the Quality Attributes, in Matlab Associated with the Importance of Each Hypothesis	Triplets Associated with the Importance of Each Hypothesis		
H1	CA = (0 × [0 0 25] + 0 × [25 25 25] + 6 × [50 25 25] + 8 × [75 25 25] + 6 × [100 25 0])/110	75	25	17.5
H2	CSN = (0 × [0 0 25] + 0 × [25 25 25] + 3 × [50 25 25] + 11 × [75 25 25] + 6 × [100 25 0])/110	78.75	25	17.5
H3	CH = (0 × [0 0 25] + 0 × [25 25 25] + 4 × [50 25 25] + 10 × [75 25 25] + 6 × [100 25 0])/110	77.5	25	17.5
H4	CSP = (0 × [0 0 25] + 0 × [25 25 25] + 6 × [50 25 25] + 8 × [75 25 25] + 6 × [100 25 0])/110	75	25	17.5
	Qt = CA(1) + CSN(1) + CH(1) + QT(1) + CSP(1);		382.5	

Table 4. Calculation of the triplets associated with the weight of the importance index of each hypothesis.

Hypotheses	Calculation of the Set of Numerical Values Associated with the Quality Attributes, in Matlab, Associated with the Importance Index of Each Hypothesis	Triplets Associated with the Importance Index of Each Hypothesis		
H1	IH1 = QC/Qt	0.1961	0.0654	0.0458
H2	IH2 = QA/Qt	0.2059	0.0654	0.0458
H3	IH3 = QG/Qt	0.2026	0.0654	0.0458
H4	IH4 = QT/Qt	0.1961	0.0654	0.0458

Table 5. The place obtained by the index of the importance of each hypothesis in the comparative analysis.

The Value Associated with the Importance of Each Hypothesis Index, CS	The Value Associated with the Importance of Each Hypothesis Index, in Descending Order, CSd	The Initial Position in the Comparative Analysis
CS1 = 70.8170	CSd1 = CS4 = 71.3521	4
CS3 = 68.7418	CSd2 = CS1 = 70.8170	1
CS3 = 68.7418	CSd3 = CS3 = 68.7418	3
CS4 = 71.3521	CSd4 = CS3 = 68.7418	2

Based on the 12th question in the questionnaire, the criteria for choosing a wine product for consumption were researched. These covered: region/area of origin, manufacturer's logo, Protected Geographical Indication inscription, inscription on the product, familiarity with the product, type of dishes with which it is consumed, quality of the product (color, taste, smell, internal and/or external appearance), the attractiveness of the packaging, price of the product. There were 5 ratings used: very important, important, indifferent, less important, and slightly important. The maximum scores for the criteria presented were obtained by the very important and important qualifiers. According to the responses, the criterion of product quality (color, taste, smell, interior and/or exterior appearance) was rated as very important, accounting for 70% of the total number of responses. The region/area of origin criterion was rated as important by 36% of respondents, the manufacturer's logo by 42%, the Protected Geographical Indication by 33%, the inscription on the product by 41%, the familiarity with the product by 50%, the type of dishes with which respondents want to consume it by 36%, the attractiveness of the packaging by 36% and the price of the product by 42%. From the information presented, it appears that when choosing a wine product, the majority of the criteria listed were given the important qualifier.

Analyzing the answer to the 13th question regarding the frequency of consumption of wine products, we recall the tradition of rural natives to grow vines and produce wine for personal consumption with family and friends. From 106 answers obtained, it was found that wine products are consumed daily by 1 person or 0.9%, weekly by 4 persons or 3.8%, monthly by 8 persons or 7.5%, on holidays (religious, national, family) by 70 persons or 66%, when meeting with friends and loved ones by 59 persons or 55.7%, and randomly (only when I want to consume wine products) by 26 persons or 24.5%. The exposed results can be seen in Figure 4.

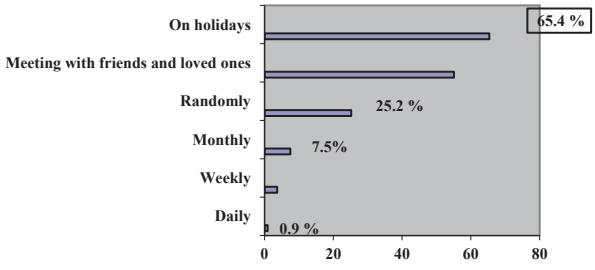

Figure 4. The frequency of consumption of wine products.

Questions 14–20 of the questionnaire, as previously mentioned, refer to wine tourism and for this reason, we will examine them more thoroughly, being objects of particular interest to the authors of this scientific research.

On the basis of the 14th question in the questionnaire, it was determined how many of the respondents surveyed had participated in organized tours of wine enterprises in the Republic of Moldova. This question was answered by 110 respondents.

Of those interviewed, 42 people or 37.5% visited only one winery, 42 people or 37.5% visited several wineries and 28 people or 25% did not visit any winery. The exposed results can be seen in Table 6.

Table 6. Share of visits to wineries.

Characteristics of Wine Visits	Percentages
The share of respondents who visited a single winery	25
The share of respondents who visited several wineries	37.5
The share of respondents who did not visit any winery	37.5

As a result, we conclude that at least 75% of the total number of respondents surveyed had visited wineries.

The next topic, researched in question 15, concerned the method of organizing the visits to wineries in the Republic of Moldova. 87 people answered this question. Thus, 68.2% or 60 persons visited the wineries on their own, 14.8% or 13 persons visited the wineries on visits organized by the tour company or tour operator, and 17% or 15 persons visited the wineries organized in combination (on their own and by the tour company or tour operator). The exposed results can be seen in Table 7.

Table 7. The organization of visits to wineries.

Characteristics of Wine Tourists	Percentages
The share of tourists who visited wineries on their own	68.2
The share of tourists who visited wineries through tour operators	14.8
The share of tourists who visited wineries in a combined way	17

The 16th multiple-choice grid question was tasked with researching what motivates visitors to visit a winery. A total of 109 respondents answered this question. The surveyed respondents went to wineries to visit a winemaking cellar, underground city or uniquely designed halls totalled 39 people or 35.8%, for wine tasting 28 people or 25.7%, to purchase wines and souvenirs at wine shops next to the factory 20 people or 18.3%, to dine at the restaurant next to the winery 20 persons or 18.3%, for accommodation in a rural area 11 persons or 10.1%, for additional activities offered by the wineries (boating, cycling, swimming pool, sauna, etc.) 21 persons or 19.3%, for the tourist attractions in the area proposed for visiting by the tourist agency 31 people or 28.4%; 36 people or 33% listed all the activities. The exposed results can be seen in Figure 5.

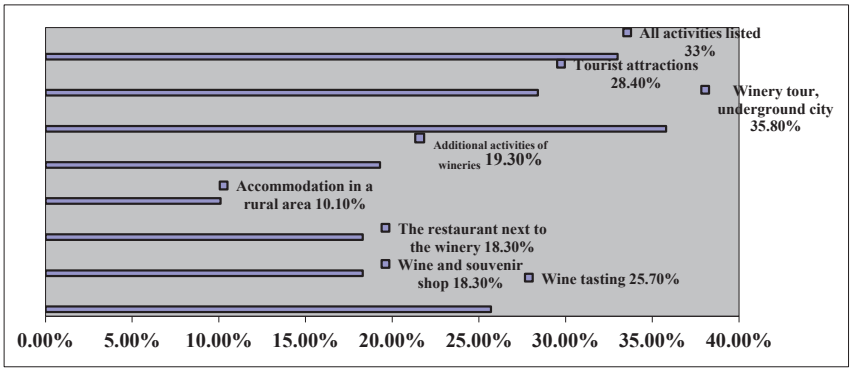

Figure 5. The composition of the tourist product of the wineries.

The 17th topic researched in the questionnaire was the name of the wineries visited by the respondents. Out of the total number of participants in the survey, 92 people visited wineries. Of these, the Cricova winery was visited by 57 people or 62.6% of the respondents, Milestii Mici was visited by 27 people or 29.7% of the respondents, the MIMI castle was visited by 20 people or 22% of the respondents, Chateau Purcari was visited by 16 people or 17.6% of the respondents, Chateau Vartely was visited by 22 people or 24.2% of the respondents, Asconi was visited by 23 people or 25.3% of the respondents, Poiana was visited by 9 people or 9.9% of respondents, other wineries were visited by 13 people or 14.3% of the respondents. The exposed results can be seen in Figure 6.

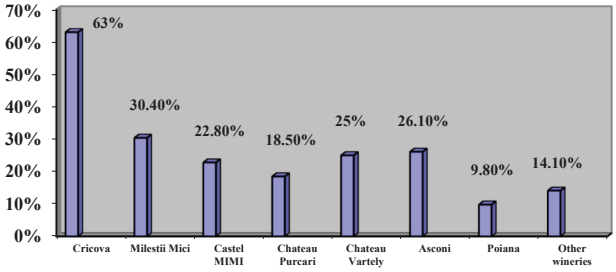

Figure 6. The number of visits of the respondents to the most popular wineries in the Republic of Moldova.

The 18th question in the questionnaire related to the intention to visit other wineries in the Republic of Moldova. Out of 106 answers, we find that 50 persons or 47.2% will visit wineries again, 34 persons or 20.8% will possibly visit wineries and 22 persons or 32.0% do not currently intend to visit wineries.

Therefore, we conclude that, out of the total number of respondents, 68% will or will consider further visiting the wineries. This result proves that wine tourism is popular among the population of the Republic of Moldova and has a tendency towards expansion.

The 19th question in the questionnaire asked about the level of satisfaction of visitors to the wineries. 91 people answered this question. The results of the survey show that 43 people or 47.3% were highly satisfied, 41 people or 45.1% were satisfied, 4 people or 4.4% were moderately satisfied, 1 person or 1.1% was less satisfied and 2 people or 2.2% were dissatisfied. The exposed results can be seen in Figure 7.

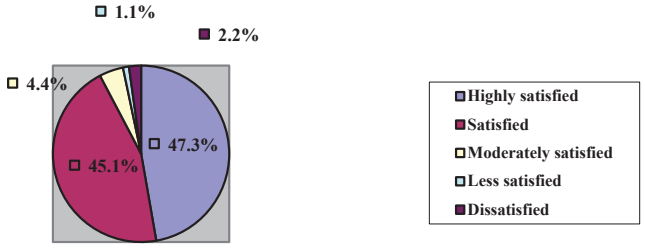

Figure 7. The level of satisfaction of visits to the wineries.

The 20th research topic was wine consumption education. Respondents were asked whether there is a need for wine education and whether this aspect is widely promoted by wineries. 86 people or 79.6% of respondents answered yes to this question, 19 people or 17.6% of respondents answered sometimes and 3 people or 2.8% of respondents answered no. From what has been reported, it can be concluded that a task of wine tourism is to promote wine consumption and educate consumers about the type of wine consumed depending on the dishes served [61–65].

5. Conclusions

Winemaking by Moldovans has been a craft from ancient times. The majority of rural households grow, produce, and serve wine. As a rule, every Moldovan event is accompanied by the serving of wine products. In the last 20 years, wine tours have become increasingly popular. As a result of going on wine tours, tourists have the opportunity to discover the beauty and richness of the centuries-old traditions of the winemaking process. At the same time, they can combine the pleasure of wine tasting with the discovery of unique itineraries and locations, with all their historical and social significance, in an exceptional natural setting such as monasteries, picturesque places, tourist attractions, rural households, workshops of folk craftsmen and so on.

The present research was carried out on the basis of a survey in order to discover the preferences of different wine consumers, to elucidate the interest of the population that participated in the survey towards trips to wineries in the Republic of Moldova, and to determine their degree of satisfaction as a result of these visits.

We believe that the opinions obtained as a result of the conducted survey can give us a fairly truthful picture of the researched questions, since respondents of different ages and levels of study participated in the survey (Table 5).

Let us establish the main conclusions and recommendations:

- Of the total number of respondents surveyed, 91.8% are consumers of wine products. Therefore, the answers obtained from the survey will allow us to discover to a fairly good degree the views of the respondents to the points covered by the questionnaire.
- Many information sources/channels (media (television, press, etc.), internet, store shelves, specialized stores, national days, festivals, exhibitions, friends/colleagues) regarding wine products are available to consumers. So the information needed by consumers can easily be found.
- Most often, wine consumers purchase wine products in specialized stores and in markets.

- Patriotism, habits passed on by parents and grandparents, recently acquired habit, suggestion of another person, simple curiosity, promotion through different channels, food safety, product characteristics (appearance, exterior, color, smell, taste, etc.), curative benefits (beneficial to health in small quantities) are important and very important reasons when wine products are chosen for consumption (Table 5).
- Important criteria in choosing a wine product include: region/area of origin, producer's logo, Protected Geographical Marking inscription about the product, familiarity with the product, type of dishes with which it is consumed, quality of the product (color, taste, smell, interior and/or exterior appearance), attractiveness of the packaging, price of the product (Table 5).
- The surveyed respondents most often consume wine products on holidays (religious, national, family) and when meeting friends and loved ones.
- Of all respondents interviewed, 75% had visited a winery and 25% had not. This fact reveals the interest of natives in visiting wineries.
- Visits to wineries were undertaken directly by 60 people or 68.2%, on the basis of combined own initiative and tour operator arrangements by 15 people or 17%, and organized by a tour operator by 13 people or 14.8%. Therefore, the majority of natives' book tours by phone or online.
- The purpose of the visit to the wineries for the surveyed respondents to a greater or lesser extent was to visit wineries, underground cities, uniquely designed rooms, tasting some wine products, purchasing wines and souvenirs, having a meal at the restaurant next to the winery, staying in rural space, additional activities offered by the wineries (boating, cycling, swimming pool, sauna, etc.), for the tourist attractions in the area, etc.
- Visiting wineries by Moldovans has become popular. The surveyed respondents visited all the wineries from personal choice. At the same time, we may mention that the most visited wineries are: Cricova and Milestii Mici.
- 68% of the surveyed respondents intend to visit the wineries again or to consider doing so. This result shows that wine tourism is popular for domestic tourists in the Republic of Moldova and has an increased interest among the population of the country.
- 47.3% were very satisfied with the visits to the wineries, and 45.1% of the respondents were satisfied. Therefore, the expectations of the surveyed visitors are justified to the extent of 92.4%.
- 97.2% of respondents believe that wine consumption education is necessary and this is a task for wine companies in the process of guiding organized tours. Therefore, the speeches presented by winery guides should contain educational information related to wines and wine consumption.

The most important factor that contributes to stimulating the consumption of wine products and wine tourism in the Republic of Moldova, according to this research, is represented by the preferred sensory hypothesis, which is followed by the hypothesis of the consumer's attitude. These factors should be analyzed in a future research study and capitalized on within a strategy for the development of wine tourism in the Republic of Moldova.

The fuzzy methodology for analyzing the importance of the factors that influence the behavior of consumers of wine products and the development of wine tourism in the Republic of Moldova is limited by the influence that manifests itself over time with changing consumption styles against the background of intercultural influences. To eliminate these limitations, the development of a neutrosophic fuzzy model is required in a future research study that will be dedicated to the analysis of intercultural influences in the Republic of Moldova.

All the results obtained tell us that in the Republic of Moldova both wine products and wine tourism are viable and popular, and the country's winemakers must constantly improve wine and wine tourism products to satisfy the needs of each consumer.

Although the present research on consumer perception of wine tourism offers an image of its potential, the current policies to support the development of wine tourism

need the involvement of institutions and local administrations to support the formation of consortia for the development of projects such as wine roads. Of course, this is difficult to organize, but without the collaboration of all the actors, the wine roads remain abandoned because the consortia are not in a position to give directions and the local administrations are not actively engaged with enhancing the heritage of wine tourism.

Author Contributions: Conceptualization, V.G., D.B. and G.A.Z. investigation, V.G., D.B. and L.Ș.; methodology, G.A.Z. and C.L.Z.; software, G.A.Z.; validation, G.A.Z.; writing—original draft, V.G. and D.B.; writing—review and editing, C.L.Z. and L.Ș.; supervision, G.A.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is contained within the article.

Conflicts of Interest: The authors declare no conflict of interest.

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Business Policy and Competitiveness of Farmers' Organizations—Empirical Evidence from Taiwan

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Abstract: Sustainable competitiveness is at the core of effective organizational management. However, the interpretation of the concept of competitiveness is quite divided, especially for organizations that are positioned as social enterprises and must bear profits and losses. In this context, we used the PLS-SEM method to discuss the impact of business policies on organizational resource management and select the Taiwanese farmers' associations for analysis. According to the resource-dependent model, we selected the corresponding variables from the existing operational competition indicators to represent the four major business sectors of these associations. The main contribution of this study is that through expert opinion, the evaluation indicators of the existing business performance competition can be integrated to define the competitiveness of farmers' associations. We also used the fuzzy C-means method cluster analysis to effectively divide 279 farmers' associations into six groups according to "population, land, and industry". It is possible to evaluate the competitiveness of the departments and business policies of the farmers' associations in different groups according to the performance of their departments. Presenting the differences in business policies will help the government implement effective counseling services between regions. Competitiveness based on the performance of the main functions significantly affects the business execution, asset allocation, marketing, and sales activities of the farmers' associations. This article clearly points out that an organization may achieve a competitive business objective by taking stock of its own operating and financial conditions. This is also true for non-profit social enterprises.

Keywords: business policy; organization performance; competitiveness; clustering; fuzzy C-means approach

Citation: Chi, S.-Y.; Hwang, T.-C.; Chien, L.-H. Business Policy and Competitiveness of Farmers' Organizations—Empirical Evidence from Taiwan. *Agriculture* **2023**, *13*, 593. https://doi.org/10.3390/agriculture13030593

Academic Editors: Hung-Hao Chang, Pei-An Liao and Jiun-Hao Wang

Received: 20 January 2023
Revised: 20 February 2023
Accepted: 24 February 2023
Published: 28 February 2023

1. Introduction

As the concept of competitiveness is highly controversial, it is often described as "confusing and unclear" [1]. An examination of recent developments in regional industrial policy in the United Kingdom reveals that competitiveness is synonymous with productivity growth [2]. As per an integrated concept of competitiveness, a competitiveness strategy is "right and useful" as long as it is effective in providing a practical function for industry [3].

The OECD suggested that "competitiveness" be understood as: " . . . the ability of companies, etc., to generate while being and remaining exposed to international competition, relatively high factor income, and factor employment levels on a sustainable basis." [4]. The World Economic Forum has defined "competitiveness" as "the set of institutions, policies, and factors that determine the level of productivity of a country, in an effort to understand and measure the drivers of economic prosperity". Blanke, et al. [5] expanded sustainable competitiveness (SCI) to make competitiveness sustainable over the longer run, in economic, social, and environmental terms.

Adopting sustainable management has been considered a critical way for companies to operate in the current business environment [6,7]. Lacy, et al. [8] survey of 766 Global

Compact member CEOs from nearly 100 countries showed that 96% of CEOs believe that sustainability issues should be fully integrated into the strategy and operations of a company. There is a positive relationship between sustainable innovation and corporate competitiveness, which can create a win–win situation for companies [9].

The competitive strategy of a firm that is active only in local marketplaces, is affected by its competitive environment naturally [10]. It requires sufficient resources to effectively enforce competition law [11]. The challenge of sustainable competitiveness is not only in designing an analytical framework but also in selecting a suitable measurement approach [12]. In short, The most important issue is to find out the factors which create the complex competitive advantage of the region regarding economic, performance, social goals, or different geographies, etc. [13].

Many successful and innovative companies now formulate their strategic business models with conventional operations such as "At Zara, the supply chain is the business model" [7]. Bublyk, et al. [14] used cluster analysis and the fuzzy C-means (FCM) clustering approach to group economic activities and identified two groups of industries in Ukraine, namely, mining, and quarrying industries and electricity, natural gas, steam, and air conditioning supply industries, as environmentally unfriendly industries, given the high degree of damage they cause to resources during the production process. Based on the findings, timely problem management was proposed as a solution for these industries. Battermann, et al. [15] analyzed the differences and conflicts among residents concerning the developmental direction during the development process in the rural areas of Lower Saxony, Germany. They confirmed the existence of cluster structures through the analysis of agricultural structures and production differences, and then recombined their findings through a discussion about the clusters to propose viable economic alternatives.

Business models are not a completely new concept [16], but are included in strategy theory [17]. Maintaining the profits of those who are connected in the supply chain is the key element to maintain long-term business success [18]; for this reason, the competitiveness reports published by the World Competitiveness Center at the International Institute for Management Development are widely used in different fields as a key to examining the enhancement of the competitiveness of countries or companies. Cluster analysis can also be used to understand the differences between technological innovation and competitiveness to develop strategic policies [19].

Rural policies in many countries have undergone major shifts over the past two decades. Agricultural policy objectives focus more on improving the competitiveness of agricultural businesses in rural areas, diversifying economic activities and finding niche markets for local products [20]. Therefore, policy is required to be effective and transferable to prompt the local farming organization to face environmental changes by improving performance [21]. If supply chain performance is an expression of national competitiveness, the businesses that finance and manage supply chains are important, especially in agriculture when it comes to food supply and quality [22].

Taiwan Farmers' Associations (TFAs) constitute the most important nonprofit organizations influencing agricultural development in Taiwan, with a history of 120 years since the first farmers' association was established in 1900. A TFA is divided into three levels according to the administrative hierarchy, each operating independently. In 2022, there were 302 associations, including 279 local TFAs (LTFAs) at the township/city/district level, with a total membership of approximately 1.7 million. However, because of the lack of a fair assessment basis and feasible guidelines to objectively diagnose the performance of local TFAs, the agricultural administration divisions are often unable to make reasonable judgments on relevant guidance and related funding subsidies, making it difficult to deal with problems in a timely and effective manner, which affects the effectiveness of the policies significantly. Accordingly, there exists an urgent need to propose an appropriate set of competitiveness indicators and locally suitable business strategies to enhance competitiveness.

Research on performance measurements are mainly divided into two categories: independent performance measurements and benchmarking [23]. Although quantitative analysis methods such as the balanced scorecard (BSC), mathematical programming [10] and data envelopment analysis (DEA) [24] are widely used in industry and research fields, they are often limited in determining the weight of individual indicators and [24,25] establishing a causal relationship with indicators [23,26,27]. The PLS-SEM method has received considerable attention in empirical research as it allows examining hypothesized associations between specific observation items and corresponding latent structures. It provides additional information on the components of organizational competitiveness by utilizing the use of hierarchical latent variable models [23,28,29].

To this end, we refer to the relevant research and use the "government-organization" interdependence framework to establish a model for diagnosing the competitiveness of farmers' organizations and the variable indicators [17]. Considering that value creation and acquisition are the key principles of business model construction, exploring external interdependencies becomes particularly important in examining the extent of critical influences on economic supply chains [17,21,30].

2. Materials and Hypothesis Development

2.1. Organization Performance (OP)

Organization performance refers to the degree of superiority in the performance of an organization relative to its competitors in terms of environmental performance, financial performance, competitiveness, and corporate reputation [31].

Organization performance can be developed and maintained through competitive advantages to explain the effectiveness of business policies. Among many studies, the resource-based view is considered to be the most rigorous method for analyzing how an organization achieves its operational goals through the use and deployment of existing resources [32]. This study examines how farmers' organizations with different resource conditions can present their competitive advantages through business policies to implement activities such as departmental business integration and execution coordination [33].

TFAs are organizations that provide economic and social services to Taiwanese farmers, who are the main members. Influenced by the Japan Agricultural Cooperatives and the American 4-H Club, LTFAs' legal missions cover almost all services, such as agricultural production technology counseling, rural life, rural industrial development, and marketing, among others. As financially autonomous nonprofit organizations, LTFAs often help to implement and promote agricultural policies and have a significant influence on rural areas. Through their role as a social enterprise, the quality of LTFA marketing activities is different from that of general profit-oriented organizations. Thus, they must maintain the necessary performance in their original services.

With societal development and the establishment of public–private partnerships, nonprofit organizations also need to have a strong service performance to respond to the competition in the external environment. Therefore, individual organizations need to demonstrate their organizational strengths through appropriate guidelines for public supervision and mutual evaluation. Several studies have summarized, from the perspective of the government's administrative guidance on the operation of TFAs, that the performance of TFAs can be formed by three main components: "operational competitiveness", "social service capability", and "policy and environmental sustainability [34–36]".

The sustainable operations management (SOM) model can provide a method for an organization to review process-level improvement drivers and allocate revenue sources through a financial and operational measurement system [7], allowing for the implementation of business policy goals. Through the organization's internal resource utilization capabilities and the implementation of economic undertakings, financial and operational indicators must effectively demonstrate the specific capabilities of farmers' associations as social enterprises to support related services with economic undertakings. This research invites the directors-general of farmers' associations and agricultural experts to jointly

select 11 indicators that effectively constitute the firm performance of Taiwan Farmers' Associations after reviewing the business and financial assessment indicators of the existing organizations to evaluate competitiveness [31].

2.2. Main Services and Resource Orchestration

According to the existing law, LTFAs not only have to provide business services, such as credit and finance, welfare insurance, product storage, processing, and sales, but also need to cooperate with government projects to promote economic and social activities, such as farming affairs, home economics, and community services. When compared with commercial enterprises, whose main business objective is to make profits, LTFAs, though functioning as nonprofit organizations, need to engage in business or adopt revenue strategies to earn income from their public service mission through the efficient application of business models [36].

How to effectively manage resources becomes a challenge. Organizations should determine the allocation of internal and external resources and how to use these resources to achieve the goals required by business owners, society, and government [31]. According to research, the stronger a company's business capability is, the higher its ability to utilize and allocate assets and personal assets will be, helping it to stand out from the competition and establish a sustainable competitive advantage through performance improvement. Resource orchestration is a necessary factor for organizations to present competitiveness [37].

As mentioned earlier, the main departments of LTFAs include promotion, credit, marketing, and insurance. Therefore, the main departmental coordination of the four departments in the organization becomes its core strategy for competitiveness. Therefore, from the perspective of organizational departments, this study examines how the competitiveness of farmers' associations is reflected by the main departmental coordination and asset condition and allocation. Accordingly, two hypotheses are proposed as follows:

H1. *The organization performance of LTFAs can be represented by the main departmental coordination.*

H2. *The organization performance of LTFAs can be represented by asset condition and allocation.*

2.3. Economy Implementation

In the face of increasingly diversified markets and organizational changes over time, the business orientation of LTFAs needs to be adjusted to meet the needs of agricultural development and farmers. Although LTFAs are positioned as social enterprises, they are still responsible for their own profits and losses. In addition to helping promote the government's agricultural policies, improving the rural economy, and taking care of farmers' welfare, the operation of their economic business departments plays a pivotal role in the local economy. Subsidies from government departments and project implementation by farmers' organizations are often seen as affirmative results for organizational competitiveness, and thus this financial assistance from the government will also affect the performance of the economic departments [38].

In addition, because of their long history and numerous assets, the allocation and revitalization of assets are very important [6,18]. In addition, after the COVID-19 pandemic, local consumers' preferences regarding sales channels and consumption methods of agricultural products have gradually changed from shopping at a wet market to shopping at supermarkets and TFA stores, where they can buy low-temperature products. Therefore, retail channels belonging to TFAs have become an important source of revenue and can meet the needs of TFAs to display and sell agricultural products.

This study proposes the following two hypotheses on whether the competitiveness of TFAs can be demonstrated with two outcomes: business marketing activities and retail activities from a business perspective.

H3. *The organization performance of LTFAs can be presented in terms of their economic marketing activities.*

H4. *The organization performance of LTFAs can be presented in terms of their retail activities.*

2.4. Clustering of Local TFAs

Agriculture is the main industry in rural areas. The development of industry, population migration, and the transformation of rural land use have changed the relationship between farmers and the land, which, in turn, has driven the development of organizational models and promoted rural development [39]. Human behavior is considered one of the direct drivers that influences and changes regional agricultural development, while industrial activity is the endogenous driving force that connects population and land and is the facilitating force for urban–rural development [39]. The boom in agritourism can lead farmers to adjust their farming activities [40].

In areas with developed industry and commerce, rural labor outflow is affected by push and pull factors, and rising land prices significantly influence rural development. Thus, the core objective of rural spatial governance is to optimize the structure of rural spatial benefits through equitable distribution while considering the development of all sectors [39,41].

The analysis of rural development from the perspective of "population, land, industry" has been widely applied to the classification and spatial governance of rural areas [39,42]. Battermann, Deimel and Theuvsen [15] adopted this viewpoint to analyze the cluster structure of rural areas in Lower Saxony, Germany. The research results support that the clearer the rural classification criteria, the easier the identification of rural clusters, especially for making decisions about economic alternatives in rural areas.

Existing studies on TFAs are mostly divided into different clusters based on geographical location, the urbanization degree of the location, and the level of profitability of the credit department. As they fail to consider the membership structure and industrial conditions of individual TFAs, they are unable to fully reflect the agriculturalization degree in their regions, making it difficult to effectively provide a basis for classification and guidance and creating a problem around financial orientation in policy guidance and competitiveness.

In other words, to demonstrate the physical performance of LTFAs through competitiveness, an appropriate clustering method can help the government develop a feasible strategy for LTFAs in response to the existing operating conditions and resource constraints of each LTFA. Only by clustering LTFAs under different conditions can the importance of each business be adjusted to improve performance.

3. Method

3.1. Constructs and Indicators

The guidelines for the OP of TFAs include 6 operational and 5 financial indicators, totaling 11 indicators. This study analyzes how business items from the perspective of organizational departments reflect the competitiveness of TFAs. Comprehensive business indicators are derived from the overall performance of the financial credit, marketing, extension, insurance, and employee contribution sectors, together with the diagnosis and evaluation of economic marketing activities, while the financial indicators reflect the quality of financial assets of the agricultural associations. The construct indicators are shown in Table 1 and Figure 1.

Table 1. Main components and variable indicators.

Latent Variables	Manifest Variables and Description	Indicator *
Main Departmental Coordination (MDC) (η_1)	TFA group scale index based on gross annual income	mdc1
	Profit of credit department	mdc2
	Total income from credit services	mdc3
	Total expenses from insurance services	mdc4
	Total expenses from extension services	mdc5
Asset Condition (AC) (η_2)	Profit of supply and marketing department	ac1
	Net value of economic department	ac2
	Net value of machines and equipment	ema1
Economic Marketing Activities (EMA) (η_3)	Total income from economic projects	ema2
	Total income from economic business	ema3
	Salary expenses from business services	ema4
Retail Activities (RA) (η_4)	Number of shopping stores and supermarkets	ra1
	Total sales of shopping stores and supermarkets	ra2
Organization performance index by combining the following 11 indicators without weight (opall)		
Organization Performance (OP) (ξ)	Total income of financial business after project income deduction	eop-1
	Total income of economic business after project income deduction	eop-2
	Contribution of employees to the output of the financial department	eop-3
	Contribution of employees to the output of the economic department	eop-4
	Resources allocated to all insurance trips by the insurance department	eop-5
	Resources allocated to all extension trips by the extension department	eop-6
	Overdue loan ratio	fop-7
	Coverage rate of bad accounts	fop-8
	Loan coverage ratio	fop-9
	Capital adequacy ratio	fop-10
	Ratio of total business income to net worth of economic department	fop-11

* All indicators are calculated with the standard deviation formula at ten scales from low to high. Date source: 2021 Annual Report, Taiwan National Farmers' Association.

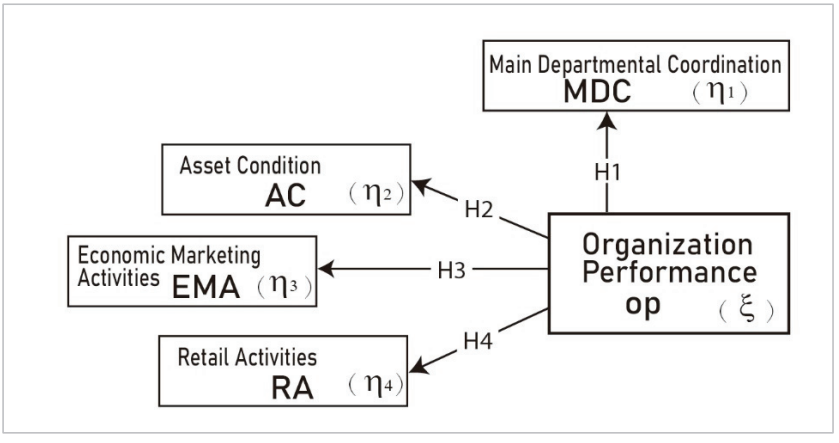

Figure 1. Constructs of main dimensions of LTFA. Source: this study.

3.2. Variable Measures

To avoid problems arising from quantitative tools, Oral and Chabchoub [10] assumed that transnational indicator values conform to a normal distribution and adopted the "standard deviation formula" to process data when analyzing the competitiveness of countries around the world by measuring the relative differences between the performances of countries to achieve a comparable effect. Because of the obvious differences in conditions among organizations, this study followed the procedure described above to evaluate the

performance indicators set by each TFA using the data from the 2021 Annual Report. The procedure was carried out as follows:

Step 1: Standardization

The study referred to the Global Competitiveness Index (GCI) to calculate the standard deviation. The formula was calculated as follows:

$$s = \sqrt{\sum (x - \overline{x})^2 \Big/ N} \quad (1)$$

where x is the indicator value, $\overline{x}$ is the arithmetic mean of the item, s is the standard deviation, and N is the total number of agricultural associations (N = 279).

Step 2: Aggregating indicators into composite indicators

The indicator value (V) of the i-th unit is then calculated as in Equation (2):

$$V_i = xi - \overline{x} \Big/ S \quad (2)$$

To facilitate comparable discussions, this study adopted deciles for the fall point analysis.

3.3. Methodology

3.3.1. Fuzzy Clustering Algorithm

Clustering is an unsupervised learning method that does not require the provision of a prior class label and instance learning. Through this method, data classification can be achieved by observational learning [43], and the effect of classification is achieved by comparing intragroup similarities and intergroup exclusion.

Because the main purpose of clustering is to find the similarity of some aspects within a group of data, different definitions of similarity produce different clustering methods, which can broadly be divided into three categories: parametric, nonparametric, and algorithmic [44]. The method based on finite mixture models [45] is parametric clustering, whereas the cluster analysis that considers density is nonparametric clustering [46]. The commonly used k-means [47], FCM, and hierarchical clustering [48] are algorithmic clustering, among which the FCM approach is quite common in social surveys and other fields, and is one of the most widely used clustering algorithms [43,49,50].

The FCM approach divides the clusters based on the degree of membership of data points to a certain class of indicators and produces a membership value between 0 and 1, indicating the membership of the analyzed values to each cluster [49]. This is different from the precise way of hard clustering that forces data points to belong to a certain class [43]. Although it is called fuzzy clustering, it has little to do with fuzzy set theory. The name mainly describes that what the approach provides is merely obtained from the membership values. Therefore, it is not a clear cluster [49]. As FCM clustering defines the sum of membership values of all clusters as equal to 1, the membership value can also be interpreted as the probability value of membership to different groups [49].

$$J_{FCM} = \sum_{j=1}^{C} \sum_{i=1}^{N} u_{ij}^{m} d_{ij}^{2}, \; m \geq 1 \quad (3)$$

where N is the number of target objects, C is the number of clusters, u_{ij} is the membership value, d_{ij} denotes distances, and m is called the fuzzifier parameter, which determines the fuzziness of the clusters. The larger the value of m, the fuzzier the clusters become; increasing the value of m means that the point sharing between all clusters increases [49,51]. When m = 1, FCM clustering degenerates to hard C-means clustering (HCM). Therefore, it is important to choose a suitable m for the FCM algorithm. Generally, we take m = 2 [43].

The algorithm of FCM is based on the minimization criterion [46], where the weighted average of each group is first calculated, and then the Euclidean distance is directly calculated to obtain it, as shown in Equation (4):

$$d_{ij}^2 = \| x_i - v_j \|^2 \tag{4}$$

The membership u_{ij} and clustering centers v_j are calculated as follows:

$$V_j = \sum_{i=1}^{N} u_{ij}^m x_i \Big/ \sum_{i=1}^{N} u_{ij}^m \tag{5}$$

$$u_{ij} = \left(\sum_{k=1}^{C} \left(\frac{d_{ij}}{d_{ik}} \right)^{\frac{2}{m-1}} \right)^{-1}, m > 1 \tag{6}$$

3.3.2. The PLS Path Model

Structural equation modeling (SEM) has been a popular quasi-standard in management research [52]. There are mainly two approaches applied to the relationship inference in SEM, i.e., covariance-based structural equation modeling (CB-EM) and partial least squares structural equation modeling (PLS-SEM). The two methods adopt different validity checks to establish models. CB-SEM is mostly used as a validation model. Therefore, the minimum measurement item covariance can be estimated only with a large sample and under the condition of the normal assignment, whereas PLS-SEM path modeling tends to be prediction-oriented [53]. Therefore, it estimates the values of latent variables via a linear combination of observed variables. It is more widely applied and has fewer [54,55] data limitations.

The use of measurements with structural equation modeling (SEM) spans a wide range of disciplines. Bollen 2011 [56] confirmed that researchers can use unstandardized and standardized coefficients as valid discriminants of models if the parameters and latent variables of the estimated indicators are valid. The PLS path modeling framework is divided into formative and reflective. Blalock (1964) referred to reflective measures as "effect indicators" and formative measures as "cause indicators" [26,56]. The observable variables are hypothesized to be a function of a latent variable. They further conclude that traditional reflective measurements are a better option for researchers in theory testing [57].

Each structural equation model consists of a measurement model, which considers the relationship between each latent variable and the corresponding variable, and a structural model, which discusses the relationship between the latent variables. In the PLS path modeling framework, the reflective measurement model can be written as [27,56]:

$$\eta_j = \gamma_j \xi + \zeta_j \tag{7}$$

$$y_i = \lambda_{ij} \eta_j + \varepsilon_i = \lambda_{ij} (\gamma_j \xi + \zeta_j) + \varepsilon_i \tag{8}$$

It shows that the effects of the construct ξ on indicator y_i are mediated by the latent variable η_j and the factor loadings λ_{ij} for the effect indicators. The indicator y_i gives a one unit difference for latent variable η_j [27,56], where i represents the indicators, λ_i refers to the loading of the i-th indicator on the latent variable, and εi represents the random error of the i-th indicator.

The PLS model can be evaluated by the nonparametric bootstrapping procedure of resampling, which involves estimating the statistical significance of the measured model path coefficients and the explanatory power of the constructs (R^2). PLS models can be assessed through tests of model fit [58].

4. Empirical Results

4.1. Fuzzy C-Means Clustering

As mentioned earlier, it is difficult to reflect the actual conditions of society and the current times on the basis of existing indicators when classifying the agriculturalization degree in townships and urban areas where LTFAs are located, leading to the dilemma that the analysis results do not fit well with practice. To reflect the conditions of LTFAs in terms of industry and natural resources, this study used the fuzzy C-means (FCM) clustering algorithm to calculate the probability of the distribution of agricultural labor (expressed as the number of people insured by agricultural insurance) and number of industrial and commercial registered households (the non-agriculturalization degree) in each township. We used "agricultural population–agricultural land–industrial activities" as the criterion for clustering. The results were then used to classify LTFAs into six clusters: A, B, C, D, E, and F (Figure 2i).

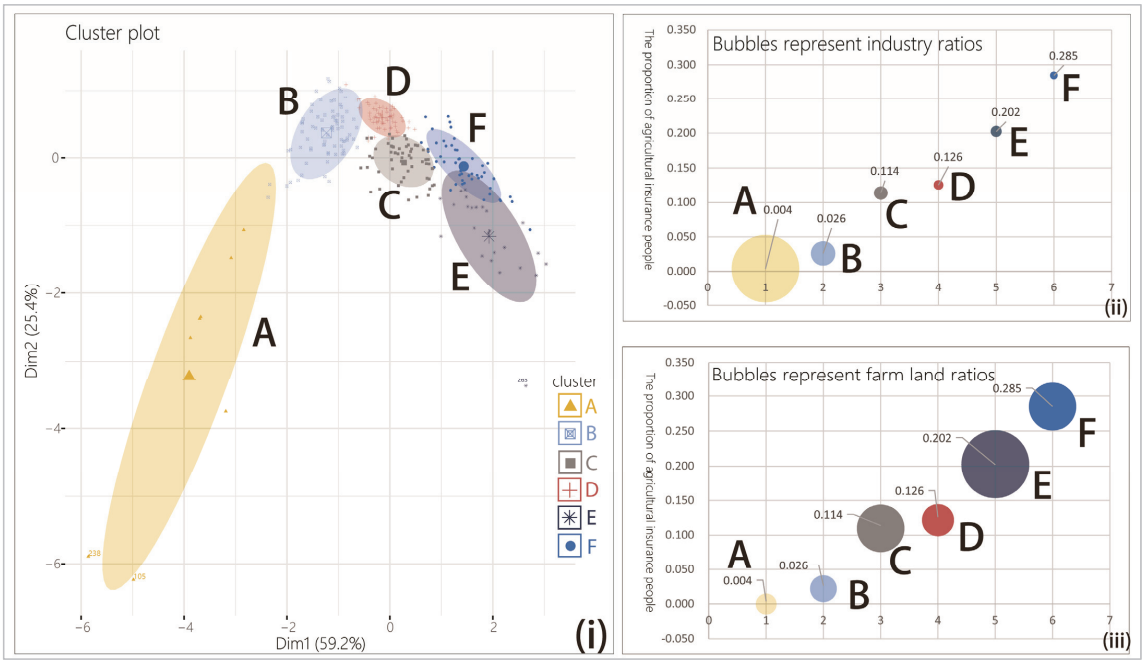

Figure 2. Classification of the probability distribution of LTFAs—scattered fuzzy C-means graph. Note: The numbers indicate the corresponding LTFAs. The circle size indicates the probability of belonging to the Cluster *i* (*i* represents A, B, C, D, E, F); the larger the circle, the higher the probability of belonging to the cluster. The color represents the probability of belonging to the cluster; the darker the color, the stronger the probability. The numbers corresponding to the bubbles in two right panels are the agricultural population ratios. Source: results obtained in this study from R.

To illustrate the differences between the subsets and their characteristics, after determining the attributes of the subsets of individual LTFAs in the above manner, the number of insured farmers in the six clusters was taken as the vertical axis. The series of six classifications was taken as the horizontal axis. The size of the bubble was used to represent the ratio of industry and commerce in the area corresponding to the classification. The larger the bubble, the higher the degree of non-agriculturalization in the area. It can be seen that the industrialization degree in Clusters A and B near the vertical axis is much higher than that in the other groups, indicating that these two clusters are quite urbanized, where Cluster A belongs to the metropolitan area, and the number of farmers and agri-

cultural land resources is not high (Figure 2ii). Clusters C and D are close to each other in terms of the number of insured farmers, but Cluster C has a higher industrialization degree than Cluster D. Cluster F, on the other hand, has a significantly higher proportion of insured farmers than the other clusters, which also indicates a fairly significant agriculturalization degree.

When considering the resource conditions of agricultural operations and replacing the proportion of industrial and commercial sectors with the proportion of agricultural land in the region, it is clear that Clusters C and E seem to have more favorable conditions for agricultural operations than Clusters D and F. This clearly divides the different clusters (Figure 2iii). The FCM results veritably provide a clear distinction over the previous classification basis, effectively and clearly clustering the 279 LFAs into six subsets to facilitate subsequent analysis.

According to the classification of practical organizations based on the six clusters, the two clusters near the left, A and B, are deeply influenced by industrial and commercial development, as they contain a very high proportion of the industrial and commercial sectors but a low proportion of the farming population. Thus, they are named as follows: Cluster A is the urban farming group, and Cluster B is the suburban farming group, indicating that the agricultural business of the area is set for consumption and environmental leisure, respectively. Clusters E and F on the right have the larger agricultural area and a higher proportion of insured farmers. They can be defined as traditional agricultural areas and belong to the farming cluster. There is a clear overlap between the two clusters, indicating that several TFAs may meet their respective conditions in terms of subcluster indicators. Clusters C and D, on the other hand, are between the urban farming cluster and the crop farming cluster and can be defined as the transition farming clusters. Cluster C has more agricultural land resources but a lower proportion of insured farmers, whereas Cluster D has fewer agricultural land resources but a higher proportion of insured farmers. The spatial distribution of the six subsets can be represented in Figure 3.

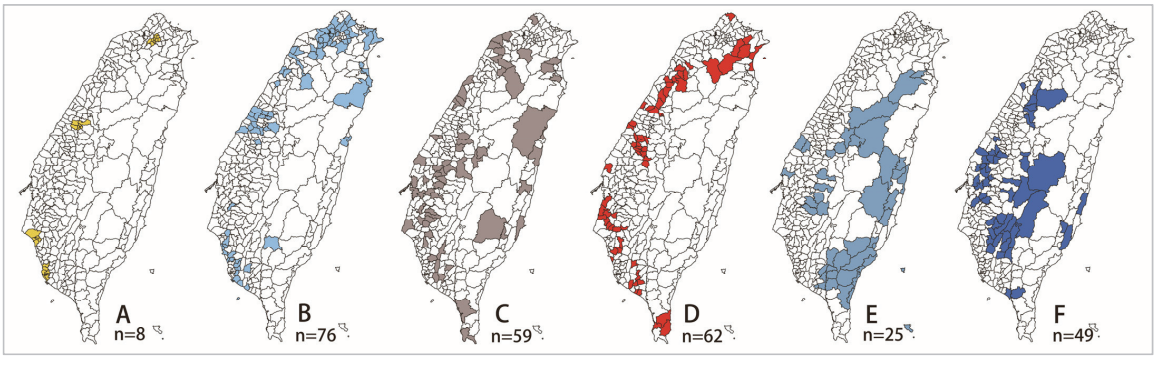

Figure 3. Spatial distribution of TLFAs in six clusters with three indicators—fuzzy C-means results. Note: A, B, C, D, E, and F represent the TLFAs clustering groups. Source: results obtained in this study from QGIS.

4.2. Assessment of the Measurement Model

In the PLS-SEM model, the reliability of the measurement model is assessed as indicator reliability and construct reliability [59]. To examine the explanatory power of factors, the standardized factor loading (SFL) of each observed variable needs to be higher than 0.4 and generally reach a threshold value of no less than 0.7. The SFL values of all the observed variables in this study ranged from 0.522 to 0.973 [54], which are in accordance with the indicator reliability, as shown in Figure 4. The composite reliability (CR) values of the variables measured in the model ranged from 0.853 to 0.908, and were all higher than the threshold value of 0.7 [60]. Therefore, the internal consistency reliability is confirmed

(Table 2). The results indicate that the average variance extracted (AVE) values that range from 0.590 to 0.748 for all observed variables are above the recommended threshold of 0.5, indicating that the model has convergent validity.

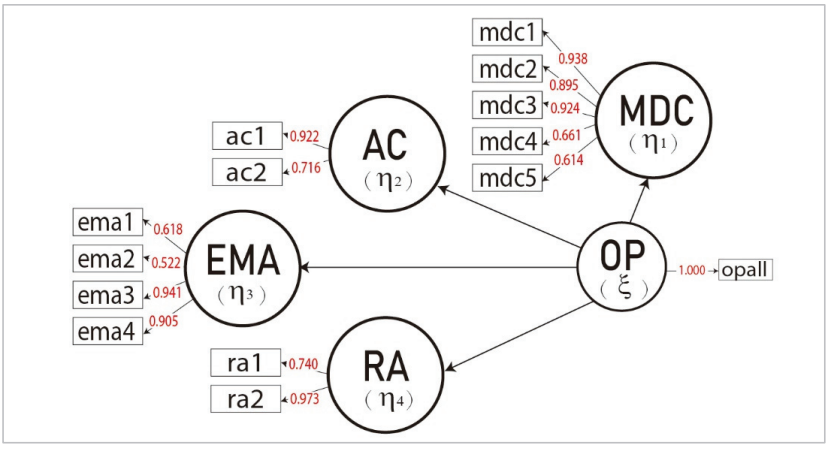

Figure 4. Indicator loadings. Source: results obtained in this study using SmartPLS 4 software.

Table 2. Construct reliability and validity.

Latent Variables	Cronbach's Alpha	rho_A	Composite Reliability (CR)	Average Variance Extracted (AVE)
Main Departmental Coordination (MDC)	0.867	0.890	0.908	0.670
Asset Condition (AC)	0.561	0.691	0.808	0.681
Economic Marketing Activities (EMA)	0.784	0.968	0.845	0.590
Retail Activities (RA)	0.722	1.365	0.853	0.748

Source: results obtained with SmartPLS 4 software.

The discriminant validity was assessed by the Fornell–Larcker criterion, and the square root of the AVE of the target variable was compared with the correlation coefficient of the latent variables. The results indicated that the square root of the AVE of individual components was higher than the correlation coefficient values of other latent variables [59,60], indicating that the model in this study has discriminant validity (Table 3). Then, by using the Heterotrait–Monotrait ratio (HTMT) of correlations proposed through the Monte Carlo simulation, the four conformational values were found to be between 0.348 and 0.792, which were in accordance with the recommendation that the check threshold value needed to be less than 0.85, and thus passed the discriminant validity.

Table 3. Discriminant validity.

Latent Variables	Fornell–Larcker Criterion					Heterotrait-Monotrait Ratio (HTMT)				
	MDC	AC	EMA	RA	OP	MDC	AC	EMA	RA	OP
Main Departmental Coordination (MDC)	0.819									
Asset Condition (AC)	0.532	0.825				0.752				
Economic Marketing Activities (EMA)	0.562	0.568	0.768			0.564	0.781			
Retail Activities (RA)	0.326	0.367	0.514	0.865		0.348	0.462	0.517		
Organization Performance (OP)	0.736	0.476	0.653	0.465	1	0.792	0.598	0.611	0.457	

Source: Results obtained with SmartPLS 4 software.

4.3. Assessment of the Structural Model

The hypothesis test of path coefficients of the PLS model can be realized by assessing model fitness through the bootstrap resampling procedure. In this study, after bootstrapping 10,000 times, the path analysis indicates that all four hypotheses are significantly valid in Table 4. The results clearly support that the main departmental coordination positively influences OP (H1: $\gamma = 0.736$), the economic asset condition positively influences OP (H2: $\gamma = 0.476$), and economic marketing activities positively influence OP (H3: $\gamma = 0.653$). The study on retail activities (H4: $\gamma = 0.465$,) also confirms their positive influence on OP, whereas for the competitiveness, it is mainly represented by the quality of the main departmental coordination (MDC), followed by economic marketing activities (EMA). Although retail activities (RA) are important, an unsatisfactory channel sales performance does not mean that a given TFA is less competitive.

Table 4. Hypothesis results.

Hyp.	Relationships	Path	SD	T Stat.	Decision	Confidence Intervals	
						2.5%	97.5%
H1	Organization Performance (OP) -> Main Departmental Coordination (MDC)	0.736	0.027	27.610 ***	Supp.	0.683	0.785
H2	Organization Performance (OP)-> Asset Condition (AC)	0.476	0.044	10.774 ***	Supp.	0.390	0.565
H3	Organization Performance (OP)-> Economic Marketing Activities (EMA)	0.653	0.028	22.964 ***	Supp.	0.599	0.710
H4	Organization Performance (OP)-> Retail Activities (RA)	0.465	0.043	10.708 ***	Supp.	0.382	0.552

Source: Results obtained with SmartPLS 4 software. *** Significant at the 0.001 level.

4.4. Result of Clustering

This study endeavored to understand the response of LTFAs with different resource conditions in terms of their OP and departmental performance. The study classified 279 LTFAs into six clusters using the classification of "agricultural population–farming land–industrial activities," which separated 8 LTFAs into Cluster A. Due to an insufficient sample size, the paths of 76 LFTAs in Cluster B, 59 in Cluster C, 62 in Cluster D, 25 in Cluster E, and 49 in Cluster F were examined. The path coefficients (γ) of each cluster were estimated separately. The results are shown in Table 5 and Figure 5.

Table 5. Hypothesis results of clustering.

Hyp.	Relationships	Cluster B		Cluster C		Cluster D		Cluster E		Cluster F	
		Path γ_b	Decision	Path γ_c	Decision	Path γ_d	Decision	Path γ_e	Decision	Path γ_f	Decision
H1	Organization Performance (OP)-> Main Departmental Coordination (MDC)	0.713 ***	Supp.	0.678 ***	Supp.	0.669 ***	Supp.	0.668 ***	Supp.	0.776 ***	Supp.
H2	Organization Performance (OP)-> Asset Condition (AC)	0.534 ***	Supp.	0.398 ***	Supp.	0.302 *	Supp.	0.342	Not Supp.	0.636 ***	Supp.
H3	Organization Performance (OP)-> Economic Marketing Activities (EMA)	0.609 ***	Supp.	0.623 ***	Supp.	0.564 ***	Supp.	0.732 ***	Supp.	0.747 ***	Supp.
H4	Organization Performance (OP)-> Retail Activities (RA)	0.506 ***	Supp.	0.255 *	Supp.	0.431 ***	Supp.	0.524 ***	Supp.	0.510 ***	Supp.

Source: Results obtained with SmartPLS 4 software. *** Significant at the 0.001 level. * Significant at the 0.05 level.

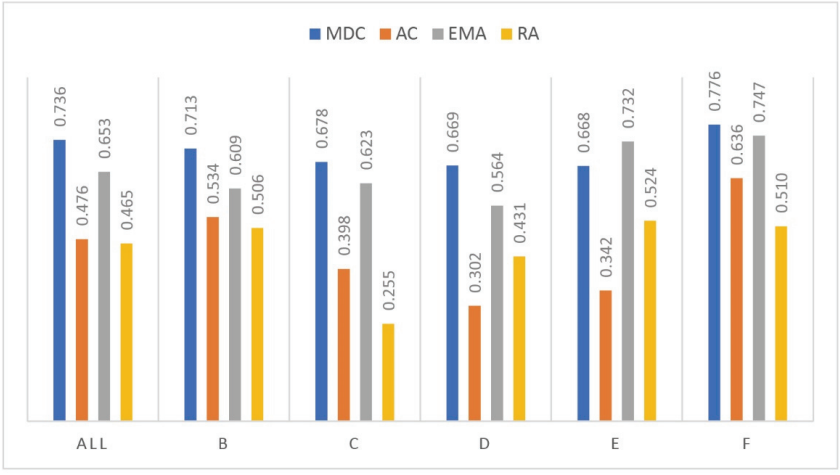

Figure 5. Structural model results of clustering. Results obtained in this study by using SmartPLS software.

All four hypotheses in Cluster B were valid, with the highest path values for departmental coordination (γ_{b1} = 0.713) and economic marketing activities (γ_{b3} = 0.609), and the explanatory power of departmental coordination is 50%. All four hypotheses in Cluster C were valid, with the highest path values for departmental coordination (γ_{c1} = 0.678) and economic marketing activities (γ_{c3} = 0.623), but retail activities were significant only at the 10% level. Cluster D had the highest path value for economic marketing activities (γ_{d3} = 0.732) and the second highest for departmental coordination (γ_{d1} = 0.669). The hypothesis of the economic asset condition does not hold. In Cluster E, the highest path values were for departmental coordination (γ_{e1} = 0.776) and economic marketing activities (γ_{e3} = 0.732). Hypothesis 2 on the relationship between organization performance (OP) and asset condition (AC) was rejected.

All four hypotheses in Cluster F were valid, with the highest path values for departmental coordination (γ_{f1} = 0.777) and economic marketing activities (γ_{f3} = 0.747), and the explanatory power of departmental coordination was 60%.

To understand the relative degree of the four main facets affected by competitiveness in different groups, Figure 5 shows the structure coefficients of OP for the four facets of the five groups of LTFAs. Results from all LTFAs (ALL) show that MDC (0.736) and EMA (0.653) were more significantly affected by OP than AC (0.476) and RA (0.465). The figure shows that there was a highly positive relationship between the competitiveness of farmers' associations that is represented by 11 performance indicators, the functional income of all departments, and the operating income of economic undertakings, whereas its relationship to economic asset conditions and entity sales channel revenue was weaker.

If we examine the structure coefficients of the individual facets of the five groups, it can be seen that except for in Cluster E, OP had a higher influence on EMA than MDC; in the other four groups, OP had a significant influence on MDC and EMA, and MDC was greater than EMA. This shows that OP is reflected in the functional performance of all departments. When OP is improved, it will result in the progress of department services, including financial, insurance, and agricultural extension services. As Cluster E belongs to a traditional farming area with characteristic agricultural products, the operation of economic business departments that provide processing and storage services often play a key function in a region; thus, EMA is an important aspect representing the competitiveness of LTFAs in the group.

In addition, the impact of OP on RA in Clusters D and E was higher than that of AC, which is obviously different from the other three groups. The results show that compared with other groups, OP had a close relationship with marketing and sales services in

Clusters D and E. Overall, Cluster F had the highest total value of structure coefficients. Except for RA (0.510), where its value was slightly lower than that of Cluster E, Cluster F's MDC, EMA, and AC were all higher than those of other groups, indicating that through the corresponding value of organizational performance, this group can effectively show good results for LTFAs in sectoral functions, economic performance, and economic asset conditions. In addition, for Cluster C, the improvement of OP was limited in helping improve marketing and sales; additionally, for Cluster D it can be seen that there is room for improvement in the use of economic assets. Relevant results can provide reference for the decision makers when adjusting resource allocation or planning competitive business policies.

5. Discussion

A hypothesis model was developed to understand the relationship between LTFAs' OP and the main departmental coordination of their business operations. The results of the study confirmed that the organization performance (OP) of LTFAs is represented by their main departmental coordination (MDC) and is directly and significantly related to their economic asset condition (AC), economic marketing activities (EMA), and retail activities (RA). In other words, the results also indicated that the OP established by the research team can effectively identify and clearly reflect the relative performance differences among LTFAs and help them to establish their own business policy to implement various economic and social goals. Our results are consistent with those previously published in the literature.

The first contribution of this study is the categorization of the separated departmental services of LFTAs into four business constructs. The OP of LTFAs has been shown to consist of two major categories, business and finance, which demonstrates the ability and role of LTFAs in providing farmers with rural and agricultural services as social enterprises through economic undertakings. Each LTFA can understand and master the key points of OP based on 11 indicators, which are conducive to the subsequent adjustment and learning in regard to their business policy.

Another contribution of this study is the classification of "agricultural population–farming land–industrial activity," which helped divide the 279 LTFAs into six clusters. Cluster B was more influenced by industrial and commercial development, whereas Cluster F had the largest agricultural population ratio (>28.5%) and had the highest explanatory power in terms of OP and the functions of each department. Cluster C had fewer industrial activities than Cluster B and a smaller agricultural population than Cluster D.

Considering that farmers' associations have the attributes of social enterprises, the public sector can refer to the classification basis of this study and provide financial subsidies or sales assistance to those who are relatively lacking according to the conditions of farmers' associations. Farmers' associations can adjust their organizational business policies and the allocation of manpower and resources in various service departments according to their own individual business advantages and organizational competitiveness to effectively meet local needs.

The objective clustering condition of "agricultural population–farming land–industrial activity" revealed that the business orientation of LTFAs in different subsets presents various competitive responses and performance levels under different environmental conditions.

The influence of the physical sales channels of TFA stores and supermarkets was relatively small, which means that the consumption habits related to market shopping need more analysis and attention. In terms of economic marketing activities, the indicators for Clusters B and D indicated that government-subsidized project plans are more important than the net value of machinery. This can probably be explained by the small amount of agricultural land and the small number of people working in agriculture, as well as by the business model that operates better with plans than it does with machinery. There will be a total of 790,000 hectares of farmland in Taiwan in 2021. Among the six groups of LTFAs, the ratio of arable land area to the national area will range from 0.09% to 0.94% on average. Cluster E had the largest area of agricultural land (>1%) among all the subsets,

but the agricultural population ratio was lower than that of Cluster F. The assumption of economic AC was not valid, indicating that the competitiveness of such TFAs should be more prudent if the AC is adopted. The OP indicator objectively describes the current year's status, grasps the differences in various indicators between OP and the natural conditions of the same group of LTFAs, and identifies the strengths through subindicators to break through operational constraints in order to have a positive influence on future operations. A complete business strategy and stable business policies are essential for not-for-profit organizations. There is no best business model, but there is a most suitable business model.

6. Conclusions

This study demonstrated that sustainable competitiveness reflects the operation and financial performance of social enterprise with diversified portfolios. By considering the data of 279 Taiwanese local farmers associations, this context examined organization competitiveness by considering their main departmental coordination, economic asset condition, economic marketing activities, and retail activities. The FCM method was conducted with regional consideration to classify the organization into six clusters with industrial development, population migration and farmland transfer as indicators.

This study results verified that the clusters established an effective classification basis to facilitating financial assistance for government. Moreover, departmental business reflects that organizational competitiveness was expected to serve the decision maker of LTFAs as a reference for adjusting the staffing and funding allocation of various services. Evidently, the complex and multivariate data from annual yearbook was effective measured and established by the FCM.

The empirical results of this paper successfully established that competitiveness indeed is related to its own operating and financial conditions and provides a diversified response to business policies. According to the results, concerns about the departmental services are crucial to the competitiveness. Therefore, considerations of the stakeholder response and cross-year comparisons should be adopted for analysis from a performance aspect.

Author Contributions: Conceptualization, S.-Y.C. and L.-H.C.; methodology, S.-Y.C. and L.-H.C.; software, S.-Y.C.; validation, S.-Y.C., T.-C.H. and L.-H.C.; formal analysis, S.-Y.C. and L.-H.C.; investigation, S.-Y.C. and L.-H.C.; data curation, S.-Y.C. and L.-H.C.; writing—original draft preparation, L.-H.C. and S.-Y.C.; writing—review and editing, L.-H.C.; visualization, S.-Y.C.; supervision, L.-H.C. and T.-C.H.; project administration, L.-H.C.; funding acquisition, L.-H.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Council of Agriculture of Taiwan (Grant No. 111 AS-1.6.1-FS-#1).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to the restrictions of the research project contract.

Conflicts of Interest: The authors declare no conflict of interest.

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Analysis of Factors Affecting Vegetable Price Fluctuation: A Case Study of South Korea

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Abstract: The fluctuation of vegetable prices in recent years underscores the need to identify contributing factors and develop effective policies. In order to examine the factors affecting the fluctuation of vegetable prices, this paper uses a structural model constructed by demand, supply, import, and export functions to decompose price variance, and also performs a numerical simulation to generalize the results. We studied the Korean vegetable market, and selected cabbage, radish, dried red pepper, garlic, and onion as research objects. The results indicates that variability of domestic production is the primary factor that influences price fluctuations in the Korean vegetable market. In contrast, our analysis revealed that demand, import, and export had a limited impact on price fluctuations in the Korean vegetable market, except for dried red pepper and onion.

Keywords: price fluctuation; Korea; vegetable price; structural model; price stabilization policy

Citation: Qiao, Y.; Kang, M.; Ahn, B.-i. Analysis of Factors Affecting Vegetable Price Fluctuation: A Case Study of South Korea. *Agriculture* **2023**, *13*, 577. https://doi.org/10.3390/agriculture13030577

Academic Editors: Jean-Paul Chavas, Hung-Hao Chang, Pei-An Liao and Jiun-Hao Wang

Received: 4 January 2023
Revised: 22 February 2023
Accepted: 24 February 2023
Published: 27 February 2023

1. Introduction

Price volatility is one of the major risks in agricultural markets. Volatile commodity prices may increase policy uncertainty, expose smallholder farmers to higher risks, alter land use, worsen the forecast accuracy of future supply and demand of agricultural commodities, and increase speculative activity in agricultural production [1]. Therefore, considerable attention has been paid to understanding price volatility in an agricultural context [2]. One strand of such in the literature has examined the factors that contribute to price volatility in agricultural commodities [3,4]. The most discussed are the effects of domestic market conditions, which include: (1) supply shortage due to changing weather conditions, (2) strong growth in domestic demand, (3) surge in energy prices, and (4) implementation of government policy [5–8].

While the extensive literature has considered the supply and demand conditions in the domestic market as a potential factor contributing to the volatile agricultural price [9,10], the importance of the trade situation has been relatively neglected. Given the surge in trading volumes of agricultural products during the last several decades, the trade volume of agricultural products may contribute to the volatility in prices [11]. Thus, it is important to examine the agricultural price volatility in the context of international trade. Nevertheless, only a few attempts have yet been made to analyze the importance of trade conditions in explaining agricultural price volatility, to the best of our knowledge [12–15]. Most of these studies mainly focus on the impact of levies-related trade policies on price fluctuations [13–15], rather than trade volumes. Therefore, we attempt to measure the effects of factors on agricultural price volatility, taking into account the trade volume.

Our model builds upon Armed and Bernard's [16] framework to analyze the factors that contribute to price volatility in the agricultural market. Our model differs from the original one in that we consider not only the domestic market conditions but also trade volumes as possible sources of price volatility.Specifically, we assume that the equilibrium price is determined by the structural equation representing the correlation between the

amount of production, consumption, export, and import. Furthermore, considering that the existing models are highly dependent on the price elasticity of supply and demand, we also conduct a numerical simulation based on the price elasticity to generalize our results.

We studied the vegetable market in South Korea for empirical analysis. The Korean market provides a suitable setting for our investigation, since the country has nationally promoted a vegetable price stabilization policy to stabilize vegetable prices [17]. Thus, in this study, we examine the factors that affect the price volatility of vegetable crops in South Korea with a particular focus on the effects of trade situations. Five main vegetables (cabbage, radish, dried red pepper, garlic, and onion) were selected as research objects because they are subject to higher risks and are the main targets of the government price stabilization policy in Korea.

Our contributions are two-fold. First, we expand the literature by exploring the effect of trade conditions on price volatility in the agricultural market. Second, our findings can bring implications for the vegetable price stabilization policy.

The remaining sections are organized as follows: Section 2 introduces a brief overview of the Korean vegetable market background, Section 3 proposes the model, Section 4 describes the data, Section 5 presents the results, and Section 6 discusses the conclusion.

2. Vegetable Production and Price Fluctuations in South Korea

Price volatility in agricultural commodities is a major issue in South Korea, and it has been pronounced in the vegetable market. Due to the weather-sensitive and cyclical nature of vegetable production, vegetable crops have been characterized by relatively high price volatility [18].In response, the South Korean government has established and implemented several treasury support programs since the 1970s to control the vegetable market situation, including (1) a price stabilization system, (2) a production contract, and (3) a reserve program [19,20]. Among them, the vegetable price stabilization, enacted in 2017, is the latest policy change to stabilize vegetable prices and support farm households [21]. The main elements of the price stabilization program are as follows: the program is targeted at seven major field crops—cabbage, radish, garlic, onion, red pepper, green onion, and potato. Among them, cabbage, radish, dried red pepper, garlic, and onion were set as the five main targets from 2018, while green onion and potato were expanded until 2020. For each crop, crisis-control manuals are constructed and mandated to help agricultural producers and stakeholders respond to various risks, such as yield variability [19]. For example, if the price falls below a threshold, farmers are subject to a partial price subsidy that guarantees 80% of the wholesale price in a normal year. Moreover, if the price drops extremely, mandates are imposed on farmers to manage excess supply, which includes: (1) export, (2) stockpiling, and (3) disposing of the oversupply.

Despite policy efforts, price fluctuations in the vegetable market persist in South Korea. As shown in Figure 1, which plots the monthly wholesale prices of five major vegetable crops in South Korea—cabbage, radish, dried red pepper, garlic and onion—from 1996 to 2020. Overall, all vegetable crops have witnessed an upward trend in wholesale prices. Furthermore, the magnitude of fluctuation in price series has been enlarged during the last decade. There has been a modest increase in the price series of cabbage and radish, and their seasonal pattern has become more extreme over the last decade. Moreover, there has been a stronger increase in prices for dried red pepper and garlic. Onion has observed a large deviation in price movements during the last decade, contrary to the past trend. Thus, it has been pointed out that the present policy should be evaluated and corrective plans should be established. Hence, revisiting the factors influencing price volatility in the vegetable market has been highlighted.

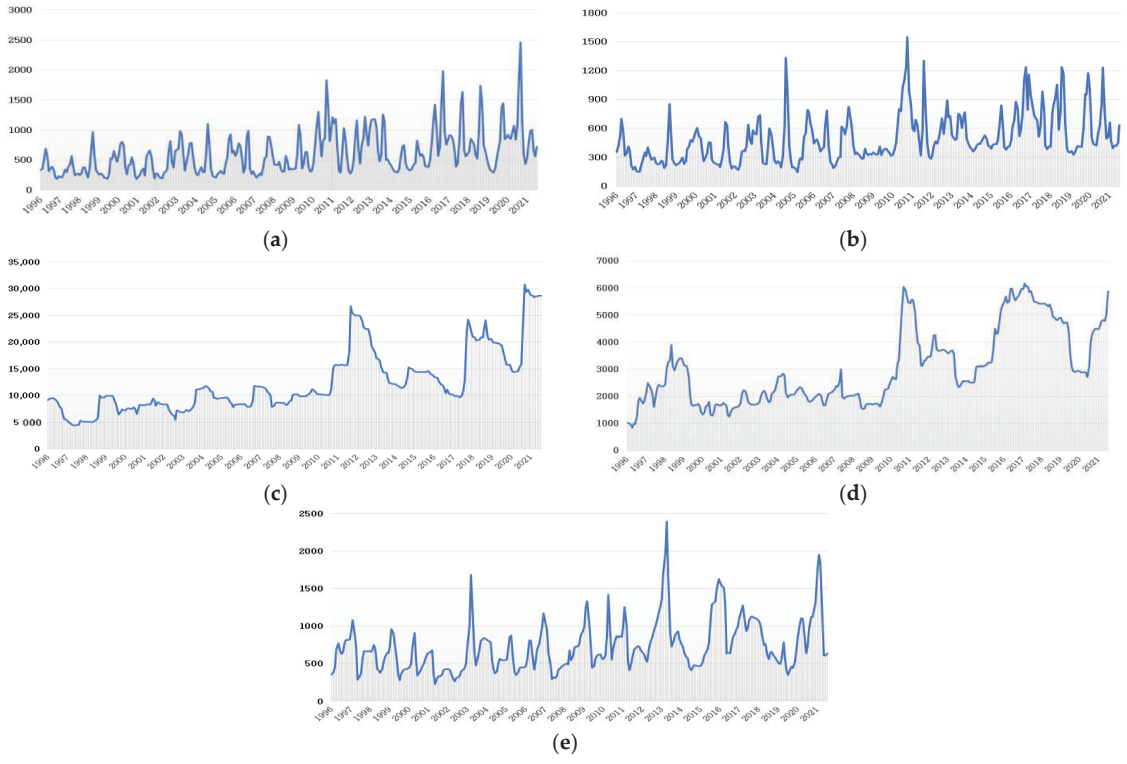

Figure 1. Monthly Wholesale Prices of Major Vegetable Crops in South Korea (in KRW/kg). Source: KAMIS (Korea Agro-Fisheries and Food Trade Corporation). (**a**) Cabbage; (**b**) Radish; (**c**) Dried Red Pepper; (**d**) Garlic; (**e**) Onion.

Figure 2 shows the annual production of five major vegetable crops in South Korea from 1990 to 2020. We presented the detailed trends of yields for cabbage and radish with respect to the harvesting season. Cabbage is classified into four types: namely, Spring Cabbage (harvested between May and June), Highland Cabbage (harvested between July and October), Fall Cabbage (harvested between November and December), and Winter Cabbage (harvested between January and May). Radishes are divided into four types: Spring Radish (harvested between June and July), Highland Radish (harvested between August and October), Fall Radish (harvested between November and December), and Winter Radish (harvested between January and May). From the figure, the annual production of onion has increased over time, while that of dried red peppers and garlic has gradually declined. Cabbage and radish have shown decreasing production trends, except for the slight temporary increase in yields for Spring Cabbage and Spring Radish during the early 2000s.

We examined the correlation between vegetable price volatility (measured by variance) and its production in the following year. Table 1 represents the result of the correlation analysis. The result revealed an inverse relationship between the two factors, except for onion. The magnitude of correlation is the largest in dried red pepper (−0.27), followed by garlic (−0.26), cabbage (−0.25), and radish (−0.17). The negative relationship between these two values implies that an increase in vegetable price volatility results in a decrease in production in the following year. This can be attributed to farmers' risk aversion, as they may take measures to mitigate their exposure to price risk, such as reducing production.

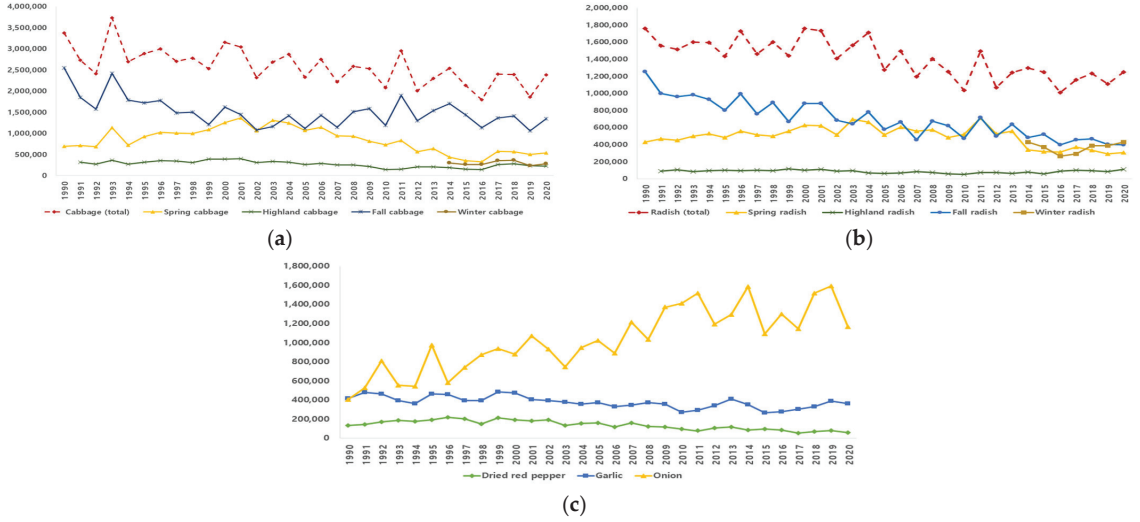

Figure 2. Annual Production of Major Field Crops in South Korea (in Ton). Source: Acreage and Production survey, Statistics Korea. (**a**) Cabbage; (**b**) Radish; (**c**) Dried red pepper, garlic, onion.

Table 1. Correlation Analysis Results: Relationship between vegetable price volatility and its production in the following year.

	Cabbage	Radish	Dried Red Pepper	Garlic	Onion
Corr. Coef.	−0.25	−0.17	−0.27	−0.26	0.38

3. Methodology

3.1. A Price Fluctuation Analysis Model

In order to examine the factors affecting vegetable price fluctuations in Korea, this paper establishes a new structural model based on the price fluctuation analysis model of Armed and Bernard [19]. This model was first used by Piggott [22] and subsequently improved by Myers and Runge [23]. However, unlike the model of Armed and Bernard, the present study considers the factors that affect vegetable price fluctuations as four factors, including demand, production, imports and exports. Specifically, our model assumes that the equilibrium price of the vegetable market is determined by the structural equations consisting of demand, production, import, and export functions and the market equilibrium equation. In addition, it is assumed that imports and exports are determined exogenously in the structural model (we have attempted to fit equations of imports and exports on price, respectively, for each vegetable, but the results show no significant relations).

Our structural model is specified as follows:

$$Q_d = a - bP \tag{1}$$

$$Q_s = c + dP \tag{2}$$

$$Q_i = e \tag{3}$$

$$Q_e = f \tag{4}$$

$$Q_d + Q_e = Q_s + Q_i \tag{5}$$

where Q_d denotes vegetable demand, Q_s denotes vegetable supply and P is the vegetable price. Q_i and Q_e denote import and export. a, c, e and f are the demand intercept, supply intercept, import intercept, and supply intercept, respectively (all exogenous demand and supply shift variables, such as agricultural product futures prices, etc., are reduced to net

intercept terms of demand and supply functions in order to reduce data and computational needs). Equation (5) is the market equilibrium equation, where the total supply is the sum of domestic supply (domestic production) and imports, and the total demand is the sum of domestic demand and exports. b and d are the constant slope parameters of the demand and supply equation, which can be rewritten as follows:

$$b = \epsilon_d \cdot (\frac{q_d}{p}) \tag{6}$$

$$d = \epsilon_s \cdot (\frac{q_s}{p}) \tag{7}$$

where ϵ_d and ϵ_s represent the price elasticities of demand and supply, representatively. p is the mean price, and q_d and q_s are the mean demand and the mean supply. Thus, b and d can be calculated by using the prior estimated elasticities and mean data of price and quantity [23].

Equations (1)–(4) can be rearranged as:

$$a = Q_d + bP \tag{8}$$

$$c = Q_s - dP \tag{9}$$

$$e = Q_i \tag{10}$$

$$f = Q_e \tag{11}$$

The system of Equations (8)–(11) and Equation (5) can be expressed as a matrix as follows:

$$\begin{bmatrix} a \\ c \\ e \\ f \end{bmatrix} = \begin{bmatrix} 11-1 & b \\ 10 & 0 & -d \\ 01 & 0 & 0 \\ 00 & 1 & 0 \end{bmatrix} \begin{bmatrix} Q_s \\ Q_i \\ Q_e \\ P \end{bmatrix} \tag{12}$$

Let Y' be the vector of $[Q_s\ Q_i\ Q_e\ P]$ and G' be a vector of net intercepts, $G' = [a\ e\ c\ f]$. Equation (12) can be written as

$$Y = A^{-1}G,\ where\ A^{-1} = \begin{bmatrix} a_{11}a_{12}a_{13}a_{14} \\ a_{21}a_{22}a_{23}a_{24} \\ a_{31}a_{32}a_{33}a_{34} \\ a_{41}a_{42}a_{43}a_{44} \end{bmatrix} \tag{13}$$

Thus, the variance of Y, $var(Y)$, is derived as

$$Var \begin{bmatrix} Q_s \\ Q_i \\ Q_e \\ P \end{bmatrix} = \begin{bmatrix} a_{11}a_{12}a_{13}a_{14} \\ a_{21}a_{22}a_{23}a_{24} \\ a_{31}a_{32}a_{33}a_{34} \\ a_{41}a_{42}a_{43}a_{44} \end{bmatrix} \begin{bmatrix} Var(a) & Cov(ac) & Cov(ae) & Cov(af) \\ Cov(ca) & Var(c) & Cov(ce) & Cov(cf) \\ Cov(ea) & Cov(ec) & Var(e) & Cov(ef) \\ Cov(fa) & Cov(fc) & Cov(fe) & Var(f) \end{bmatrix} \begin{bmatrix} a_{11}a_{12}a_{13}a_{14} \\ a_{21}a_{22}a_{23}a_{24} \\ a_{31}a_{32}a_{33}a_{34} \\ a_{41}a_{42}a_{43}a_{44} \end{bmatrix} \tag{14}$$

The variance of equilibrium price $var(P)$ can finally be calculated as the following Equation (15):

$$\begin{aligned} Var(P) = {} & a_{41}^2 Var(a) + a_{42}^2 Var(c) + a_{43}^2 Var(e) + a_{44}^2 Var(f) + 2a_{41}a_{42}Cov(ac) \\ & + 2a_{41}a_{43}Cov(ae) + 2a_{41}a_{44}Cov(af) + 2a_{42}a_{43}Cov(ce) \\ & + 2a_{42}a_{44}Cov(cf) + 2a_{43}a_{44}Cov(ef) \end{aligned} \tag{15}$$

where the variance of price $var(P)$ consists of the variances of a, c, e, and f, which are the intercepts of the supply function, the demand function, the import function, and the export function, and their covariances. It implies that the price variance is directly

attributable to the demand, supply, import, export and their interactions. In other words, $a_{41}^2 Var(a)$, $a_{42}^2 Var(c)$, $a_{43}^2 Var(e)$, $a_{44}^2 Var(f)$ in Equation (15) represent the direct effects of production, demand, import and export, respectively, and the covariance part can be interpreted as the interaction effects of production, demand, import and export. Thus, the ratio obtained by dividing each variance term of production, demand, import and export by the price variance represents the contribution of each factor to the price fluctuation (notably, since our model is not a structural econometric model, it is difficult to separately estimate the impact of other exogenous variables on price fluctuations or volatility clustering effects such as time series models, for example the GARCH model, which can be regarded as a limitation of our study. In addition, our model is limited in its ability to explore seasonality due to its characteristic features, which can be considered to be another limitation).

3.2. A Numerical Simulation

From the above model, it can be easily identified that the variance of price is directly affected by the demand elasticity and the supply elasticity. Therefore, in order to more accurately grasp the influencing factors of vegetable price fluctuation, we conduct a numerical simulation based on these two parameters. We vary the magnitude of these two important parameters to examine the impact of different factors on price fluctuations. Specifically, we proceed with numerical simulations by appropriately scaling up or scaling down the available price elasticity data that have been widely used.

4. Data

This paper takes Korea as an example and uses the annual production, wholesale price, import and export data to analyze the main influencing factors of vegetable price fluctuation during the past 20 years (2001–2020). As mentioned, we select five main vegetables—cabbage, radish, dried red pepper, garlic and onion—as research objects. Cabbage and radish are analyzed separately by crop type. That is, cabbages are classified into spring cabbage, highland cabbage, fall cabbage, and winter cabbage, and radish is classified into spring radish, highland radish, fall radish, and winter radish. The production data were collected from the Crop Production Survey of Statistic Korea, and the wholesale price data were collected from the KAMIS (Korea Agricultural Marketing Information Service) website [24] of the Korea Agro-Fisheries and Food Trade Corporation. KAMIS contains agricultural wholesale market information, where all wholesale price information includes prices for two qualities of vegetables: high-grade and middle-grade. The price used in this study is the calculated average of these two qualities of vegetable prices. All vegetable import and export data were collected through the "Korea Customs Service Trade Statistics" website [25].

Table 2 shows descriptive statistics of the variables used in our model. For production, fall cabbage is the highest, followed by onions, spring cabbage, and winter radish. The average wholesale price is highest in order of dried red pepper, garlic, onion and fall radish. In terms of import volume, dried red peppers are the most imported, and spring cabbage is the least. In terms of export volume, onions with the largest production also have the largest exports, and dried red peppers are hardly exported.

Table 3 provides the supply and demand elasticities of five main vegetables used in this study. All supply and demand elasticities used in this study were obtained from the Korea Agricultural Simulation Model (KASMO) developed by the Korea Rural Economic Institute (KREI) in 2020 (more details about KASMO can be found in Seo et al. [26]). The KASMO is a simultaneous, non-spatial, partial equilibrium model and it is constructed to be generally used as an official tool for analyzing various policy issues related to agriculture and forecasting future prices of commodities in Korea [27]. It was first developed in 2008 and has been re-estimated and re-specified every year to reflect changes in the Korean agricultural sector. In particular, the supply and demand elasticities estimated from the KASMO are currently used for the annual outlook of Korean agriculture.

Table 2. Descriptive statistics of the variables.

			Mean	S.D.	Min	Max
Production (unit: ton)	Cabbage	Spring cabbage	806,849.1	325,456.6	321,649	1,357,357
		Highland cabbage	238,030.2	71,499.3	136,504	399,151
		Fall cabbage	1,360,443.0	221,648.1	1,059,925	1,896,828
		Winter cabbage	291,149.8	52,810.6	227,250	358,501
	Radish	Spring radish	355,836.8	63,961.2	263,976	428,760
		Highland radish	501,536.9	135,173.5	291,506	710,416
		Fall radish	78,392.7	15,615	55,382	113,121
		Winter radish	572,814.3	137,036.5	396,605	881,526
	Dried red pepper		113,389.6	39,860.2	55,714	192,753
	Garlic		346,205.6	44,288.5	266,272	412,250
	Onion		1,203,284.0	244,288.6	745,203	1,594,450
Wholesale price (unit: KRW/kg)	Cabbage	Spring cabbage	488.3	197.9	273.3	954.8
		Highland cabbage	834.5	320.7	419.5	1614.3
		Fall cabbage	514.3	219.2	227.3	910.3
		Winter cabbage	608.9	301.0	221.8	1147.0
	Radish	Spring radish	450.8	182.1	214.7	795.3
		Highland radish	513.0	164.3	234.3	898.3
		Fall radish	691.6	252.1	352.8	1297.7
		Winter radish	505.5	251.6	196.3	1062.3
	Dried red pepper		13,144.4	4714.8	7119.0	22,182.0
	Garlic		3185.5	1339.3	1565.0	5743.0
	Onion		750.0	239.5	373.0	1253.0
Import volume (unit: ton)	Cabbage	Spring cabbage	85.4	176.5	0.0	780.2
		Highland cabbage	1471.3	2700.3	0.0	11,533.8
		Fall cabbage	256.6	478.2	0.0	1887.7
		Winter cabbage	724.0	1735.1	0.0	6745.3
	Radish	Spring radish	1708.9	2057.4	0.0	6240.3
		Highland radish	336.4	462.7	0.0	1645.6
		Fall radish	1058.6	1486.6	0.0	5735.3
		Winter radish	1700.4	2012.3	0.2	7953.2
	Dried red pepper		164,571.6	63,664.8	49,148.7	246,967.3
	Garlic		14,050.2	10,714.4	3109.3	37,049.6
	Onion		47,262.9	42,068.5	751.2	157,640.2
Export volume (unit: ton)	Cabbage	Spring cabbage	2909.6	3115.6	162.5	9329.2
		Highland cabbage	2736.0	2472.2	137.5	10,400.8
		Fall cabbage	2476.5	2869.2	17.9	10,131.2
		Winter cabbage	2096.9	2900.9	13.4	11,623.8
	radish	Spring radish	1314.0	1171.6	53.8	4481.5
		Highland radish	69.6	142.6	1.8	535.4
		Fall radish	92.8	128.0	0.0	571.4
		Winter radish	821.0	790.4	9.9	2415.3

Table 2. *Cont.*

		Mean	S.D.	Min	Max
	Dried red pepper	38.6	126.0	0.0	539.3
	Garlic	1049.2	2482.5	9.3	11,064.7
	Onion	5709.1	11,939.7	0.6	50,409.9

Note: For import and export, dried red pepper includes fresh dried red pepper (HS code: 090421000) and frozen dried red pepper (HS code: 090421000). Garlic includes peeled garlic (HS code: 0703201000), fresh gutted garlic (HS code: 0703209000) and frozen garlic (HS code: 0710802000). Onion includes fresh chilled onion (HS code: 0703101000) and frozen onion (HS code: 0710801000).

Table 3. The supply and demand elasticities of 5 main vegetables.

		Spring	Highland	Fall	Winter	Dried Red Pepper	Garlic	Onion
Supply	Cabbage	0.28	0.62	0.29	0.44	0.5	0.85	0.61
	Radish	0.48	0.23	0.8	0.86			
Demand	Cabbage	−0.74	−0.18	−0.41	−0.73	−0.67	−0.50	−0.59
	Radish	−0.36	−0.24	−0.37	−0.62			

5. Results

This study analyzed the direct and interaction effects of supply (production), demand, import and export of five main Korean vegetables. In order to better grasp the effects in different periods, we analyzed the influencing factors of the vegetable price fluctuation in the last 20 years (2001–2020), the 2010s (2011–2020), and the last 5 years (2016–2020), respectively. The results are presented in Section 5.1. Afterward, considering those direct and interaction effects directly attributable to demand and supply elasticities, we performed a numerical simulation. By varying the magnitude of the elasticity, we simulated different results in the influence of different factors on price fluctuations. The results are presented in Section 5.2.

5.1. Price Fluctuation Analysis Results

5.1.1. Cabbage

Table 4 reports the price fluctuation analysis results of cabbage, including the direct and interaction effects of production, demand, import and export on cabbage price fluctuation. The results show that, except for the fall cabbage, the other three types of cabbage price fluctuations of the last 20 years are all characterized by a large positive direct effect and a relatively small negative interaction effect. However, for all four types of cabbage, the direct effects of production, demand, import and export are all greater than the interaction effects in all three periods.

From the results of direct effects, supply variability has the largest contribution to the price fluctuations of all types of cabbage in the last 20 years. In other words, supply variability was the dominant force behind Korean cabbage price volatility, especially fall cabbage. The results also show that fluctuations in supply and demand can explain almost all price variations of cabbage in recent years, since trade fluctuations have very little effect. However, in terms of the influencing factors of cabbage price fluctuations in the past 10 years and the past five years, except for fall cabbage, the effect of supply of other types of cabbage has weakened to a certain extent. The price fluctuations of fall cabbage in the past five years were almost entirely affected by supply variations. Furthermore, our results indicate that price fluctuations of different types of cabbage are affected differently by supply and demand, and these effects vary over time, which is also worthwhile to note.

Table 4. Price fluctuation analysis results of cabbage.

		Total Effect			Decomposition of Direct Effect				
		Direct Effect	**Interaction Effect**	**Total**	**Demand**	**Supply**	**Import**	**Export**	**Total**
Spring cabbage	The last 20 years (2001–2020)	204.98	−104.98	100	33.65	66.34	0.00	0.00	100
	The 2010s (2011–2020)	131.59	−31.59	100	40.21	59.78	0.00	0.01	100
	The last 5 years (2016–2020)	97.45	2.55	100	49.34	50.64	0.00	0.02	100
Highland cabbage	The last 20 years (2001–2020)	283.53	−183.53	100	29.87	70.04	0.05	0.04	100
	The 2010s (2011–2020)	181.10	−81.10	100	58.62	41.23	0.01	0.14	100
	The last 5 years (2016–2020)	694.58	−594.58	100	39.73	60.25	0.00	0.02	100
Fall cabbage	The last 20 years (2001–2020)	98.71	1.29	100	21.77	78.22	0.00	0.01	100
	The 2010s (2011–2020)	124.48	−24.48	100	9.99	90.00	0.00	0.01	100
	The last 5 years (2016–2020)	140.00	−40.00	100	5.84	94.15	0.00	0.01	100
Winter cabbage	The last 20 years (2001–2020)	119.90	−19.90	100	32.49	67.48	0.01	0.03	100
	The 2010s (2011–2020)	98.71	1.29	100	32.49	67.48	0.01	0.03	100
	The last 5 years (2016–2020)	122.69	−22.69	100	79.50	20.42	0.00	0.09	100

5.1.2. Radish

Table 5 summarizes the price fluctuation analysis results of four types of radishes. The results show that, except for the winter radish, the other three types of radish price fluctuations of the last 20 years are all characterized by a large positive direct effect and a small negative interaction effect. For all four types of radish, the direct effects of production, demand, import and export are all greater than their interaction effects in all periods.

From the results of direct effects, supply variability has the largest contribution to the price changes of all types of cabbage in the past 20 years. Especially for fall radish and winter radish, the supply variation is found to be able to explain 91.99% and 83.27% of its price fluctuation, respectively. However, the effect of supply changed in the 2010s and the last five years. Surprisingly, the price fluctuations of spring radishes over the last five years have been more affected by demand variations, while in the last 10 and 20 years they have been more affected by supply. Highland radishes were also found with similar results. In addition, the impact of import variation was also found in the price fluctuations of highland cabbage, albeit a small proportion. Moreover, like cabbage, the price fluctuations of different types of radishes are affected by different factors. Such results are helpful for the government to formulate corresponding price stabilization policies.

5.1.3. Dried Red Pepper

Table 6 shows the results of the price fluctuation analysis of dried red pepper, including the direct and interaction effects of supply, demand, import and export on dried red pepper price variation. The results show that, for all three periods, dried red pepper price fluctuation is characterized by a large positive direct effect and a comparably small negative

interaction effect. This direct effect is the largest in the period of last 20 years and smallest in the last five years.

Table 5. Price fluctuation analysis results of radish.

		Total Effect			Decomposition of Direct Effect				
		Direct Effect	Interaction Effect	Total	Demand	Supply	Import	Export	Total
Spring radish	The last 20 years (2001–2020)	279.13	−179.13	100	35.27	64.73	0.00	0.00	100
	The 2010s (2011–2020)	1004.71	−904.71	100	48.41	51.59	0.00	0.00	100
	The last 5 years (2016–2020)	130.27	−30.27	100	72.49	27.51	0.00	0.00	100
Highland radish	The last 20 years (2001–2020)	354.38	−254.38	100	49.51	50.16	0.33	0.00	100
	The 2010s (2011–2020)	585.21	−485.21	100	66.94	32.50	0.56	0.00	100
	The last 5 years (2016–2020)	400.70	−300.70	100	62.18	37.75	0.07	0.00	100
Fall radish	The last 20 years (2001–2020)	111.48	−11.48	100	8.01	91.99	0.00	0.00	100
	The 2010s (2011–2020)	100.97	−0.97	100	10.69	89.30	0.01	0.00	100
	The last 5 years (2016–2020)	67.81	32.19	100	8.88	91.11	0.00	0.00	100
Winter radish	The last 20 years (2001–2020)	73.55	26.45	100	16.71	83.27	0.01	0.00	100
	The 2010s (2011–2020)	73.55	26.45	100	16.71	83.27	0.01	0.00	100
	The last 5 years (2016–2020)	104.35	−4.35	100	20.69	79.30	0.00	0.01	100

Table 6. Price fluctuation analysis results of dried red pepper.

	Total Effect			Decomposition of Direct Effect				
	Direct Effect	Interaction Effect	Total	Demand	Supply	Import	Export	Total
The last 20 years (2001–2020)	226.39	−126.39	100	58.87	15.11	26.02	0.00	100
The 2010s (2011–2020)	165.19	−65.19	100	68.97	11.12	19.91	0.00	100
The last 5 years (2016–2020)	129.43	−29.43	100	84.38	6.93	8.68	0.00	100

From the results of direct effects, demand contributed most to the dried red pepper price variation in three periods, especially in the 2010s. Considering the storability of dried red pepper, it can be said to reflect the characteristics of the market by the result that the main influencing factor of price fluctuations is demand. In addition, compared with the 2010s, the proportion of price fluctuations explained by demand is found to be higher in the past five years. Moreover, it is worth noting that the contribution of import variability to dried red pepper price fluctuations is relatively higher than that of supply. It can be explained by the relatively high import dependence on dried red pepper. In Korea, imports of dried red pepper are higher than domestic production.

5.1.4. Garlic

Table 7 shows the results of the price fluctuation analysis of garlic. The results show that garlic price fluctuations of two periods, the last 20 years and the 2010s, are characterized by a large positive direct effect, and a small positive interaction effect. However, in the last five years, the interaction effect has a negative sign, which indicates that the negative interaction effects of supply, demand, import and export on garlic price variation became larger in recent years.

Table 7. Price fluctuation analysis results of garlic.

	Total Effect			**Decomposition of Direct Effect**				
	Direct Effect	**Interaction Effect**	**Total**	**Demand**	**Supply**	**Import**	**Export**	**Total**
The last 20 years (2001–2020)	69.60	30.40	100	14.63	84.61	0.74	0.02	100
The 2010s (2011–2020)	94.27	5.73	100	9.77	88.47	1.75	0.01	100
The last 5 years (2016–2020)	108.47	−8.47	100	2.97	94.89	2.12	0.02	100

From the results of direct effects, the contribution of supply variability to the price fluctuation of garlic is largest in all three periods, followed by demand, import and export. This effect of domestic production has increased strongly in recent years. In particular, 94.89% of the direct effects of garlic price fluctuations in the last five years can be explained by factors of domestic production. The price volatility of garlic has increased over the past decade in Korea. Therefore, considering our results, it can be suggested that managing domestic production would be the most effective policy to stabilize garlic prices in Korea.

5.1.5. Onion

Table 8 shows the results of the price fluctuation analysis of onion. Onion price fluctuation of the last 20 years is characterized by a large positive direct effect of demand, domestic production, import and export, and a comparably small negative interaction effect. However, in the 2010s and the last five years, onion price fluctuation is characterized by a large positive direct effect and a small positive interaction effect.

Table 8. Price fluctuation analysis results of onion.

	Total Effect			**Decomposition of Direct Effect**				
	Direct Effect	**Interaction Effect**	**Total**	**Demand**	**Supply**	**Import**	**Export**	**Total**
The last 20 years (2001–2020)	109.25	−9.25	100	53.30	45.91	0.74	0.06	100
The 2010s (2011–2020)	89.65	10.35	100	12.42	86.02	1.42	0.14	100
The last 5 years (2016–2020)	92.78	7.22	100	6.74	91.80	1.25	0.21	100

For the direct effects of onion price variation, the results over the last 20 years differ significantly from those in the 2010s and the last five years. In recent years, supply and demand play important roles in price fluctuations, whereas trade plays a smaller role. However, over the last 10 years, especially in the last five years, domestic production has played the most important role and the effect of trade has also slightly increased. This indicates that the explanatory power of domestic production for onion price fluctuation in the last five years has reached 91.8%. Thus, like garlic, in order to stabilize the ever-increasing price fluctuations of onions, it would be more effective for the government to formulate supply-side policies.

5.2. Numerical Simulation Results

We performed numerical simulations based on the demand and supply elasticities of five main vegetables. For each vegetable, we increased and decreased the price elasticity by 10%, 20%, and 30% to examine the change of direct effects of demand, supply, import and export on the price fluctuation. We only compared the simulation results for the last 20 years in this subsection.

Figure 3 presents the simulation results of four types of cabbage. It shows the results of the direct effects of demand, supply, import and export using the existing demand and supply elasticities of cabbage, and the results using the 10%, 20%, and 30% increase and decrease in the price elasticities. For spring cabbage, the direct effect of demand on price fluctuation caused by varying the price elasticity ranges from 33.65% to 35.35%, and the effect of supply ranges from 64.75% to 66.34%. The effects of import and export are small and hardly vary with elasticities. However, for highland cabbage, the direct effect of demand on price fluctuation ranges from 24.86% to 35.86% and the effect of supply ranges from 64.04% to 75.57%. It can be seen that the direct effects of demand and supply vary greatly when price elasticities change. However, the contribution of supply variability to price fluctuations is still higher than that of demand and trade volume. In addition, for fall cabbage and winter cabbage, the change of the simulated elasticity has little effect on the change of the proportion of the influencing factors of price fluctuation. It indicates that supply variability explains more price fluctuations of these two types of cabbage.

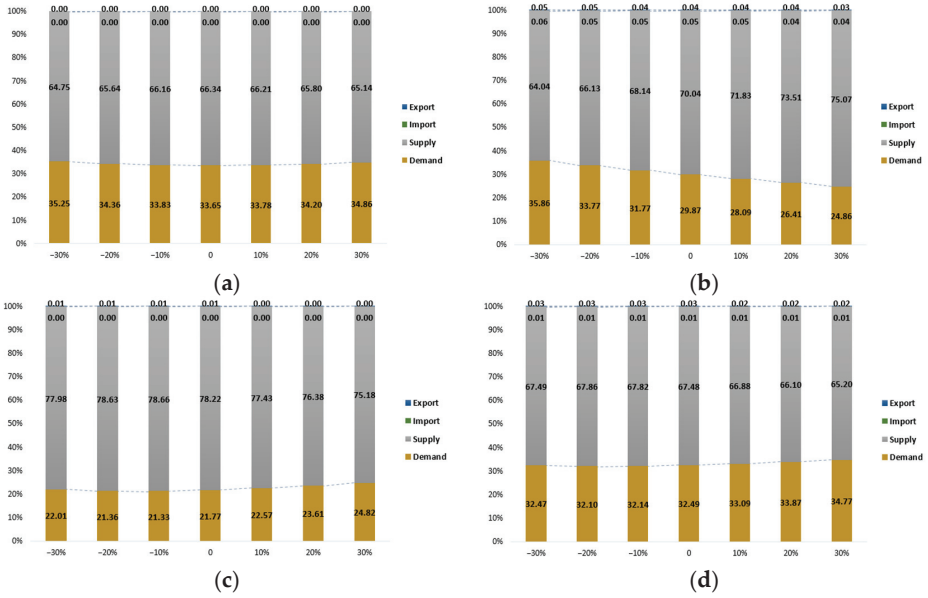

Figure 3. Numerical simulation results of cabbage. (**a**) Spring cabbage; (**b**) Highland cabbage; (**c**) Fall cabbage; (**d**) Winter cabbage.

Figure 4 presents the simulation results of four types of radish. For spring radish, the direct effect of demand on price fluctuation ranges from 32.27% to 39.1%, and the effect of supply ranges from 60.90% to 67.73%. The effects of import and export are almost close to zero in all simulations. For highland radish, the contribution of supply and demand variabilities to price fluctuations are similar and barely changed in all simulations. In addition, for fall radish, although the direct effects of demand and supply on price fluctuations vary with the change of elasticities, the influence of demand is the largest among the four factors, ranging from 87.96% to 93.32%. For winter radish, supply variability

plays the most important role in price fluctuations, ranging from 81.64% to 83.84 in all simulations, which is similar to fall radish.

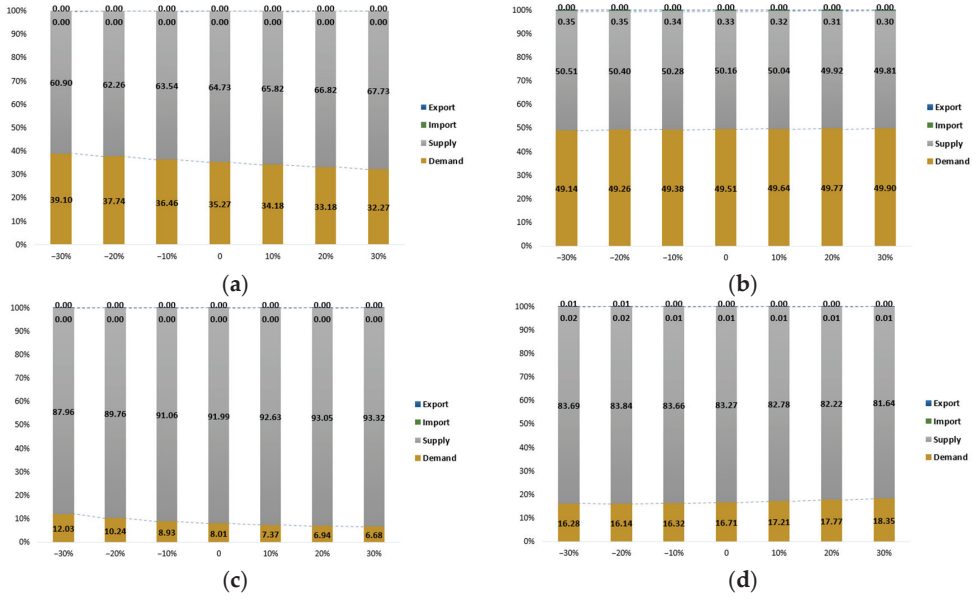

Figure 4. Numerical simulation results of radish. (**a**) Spring radish; (**b**) Highland radish; (**c**) Fall radish; (**d**) Winter radish.

Figure 5 shows the simulation results of dried red pepper. In all simulations, the direct effect of demand on price fluctuation ranges from 50.37% to 65.23%, which is higher than that of the other three factors. It indicates that demand contributed most to the dried red pepper price variation, although price elasticities change. In addition, it should be noted that the contribution of import variation can reach a maximum of 33.86% with the change in price elasticity. Thus, import variation can explain the price fluctuations of dried red pepper better than supply variation.

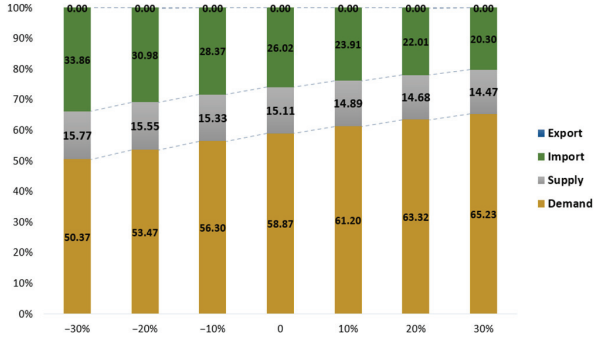

Figure 5. Numerical simulation results of dried red pepper.

Figure 6 depicts the simulation results of garlic. The results show that the direct effect of supply on price fluctuation ranges from 82.39% to 87.15%, which is the largest among the four influencing factors. It indicates that supply variability was the dominant force behind the price fluctuations of garlic in the past. Secondly, the contributions of demand and import variation to garlic price fluctuations were found to range from 11.53% to 17.13%

and 0.47 to 1.27%, respectively. In addition, the effect of export on price variation is the smallest among all the simulation results.

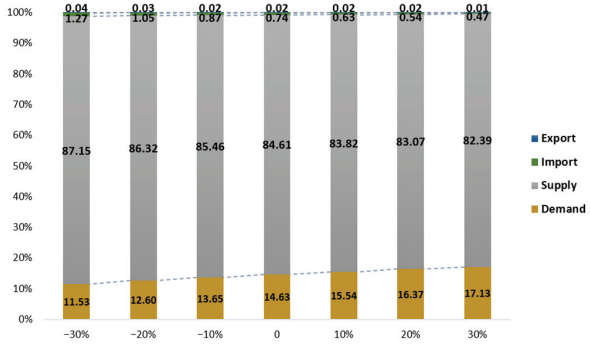

Figure 6. Numerical simulation results of garlic.

Figure 7 depicts the simulation results of onion. From these results, the contributions of supply and demand variabilities to price fluctuations are barely changed in all simulations, although demand plays a slightly more important role. In addition, the direct effects of import and export variations on the onion price fluctuation are less than 1%; relatively small.

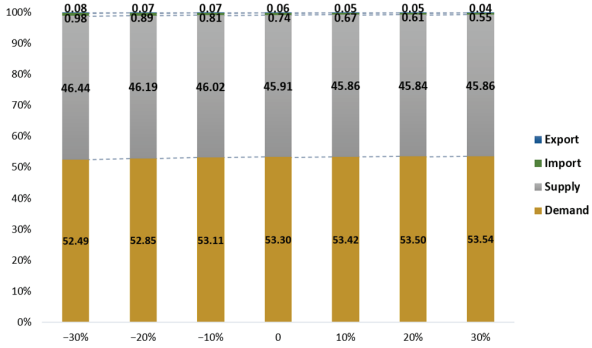

Figure 7. Numerical simulation results of onion.

6. Summary and Conclusions

Price volatility in the vegetable market is a significant global concern. This paper takes South Korea as an example to study the factors affecting price fluctuations of major vegetables—cabbage, radish, dried red pepper, garlic, and onion. We took three time periods, the last 20 years (2001–2020), the 2010s, and the last 5 years, to analyze the effect of demand, supply, import and export factors on the price fluctuations of vegetables in different periods by using a structural price fluctuation analysis model. We further conducted numerical simulations on the elasticity of supply and demand of different vegetables to examine the changes in the factors that affect price fluctuations. Our results are summarized as follows:

First, fluctuations in vegetable prices can be attributed to the direct and interaction effects of demand, supply, import and export, and the direct effect is generally positive and larger than the interaction effect. Second, except for dried red pepper and onion, the direct effect of production fluctuations contributed most to the price fluctuations of vegetables of the last 20 years, while the effects of demand, import and export had relatively low explanatory power regarding price fluctuations. However, for dried red pepper and onion, of which the storage period is, relatively, longer, demand variations play more important roles in price fluctuations than production fluctuations. Specifically,

for dried red pepper, import contributed more than production in the last 20 years. Third, compared to the 2010s, except for spring/winter cabbage, spring/winter radish and dried red pepper, the proportion of price fluctuations explained by the production fluctuations of other vegetables was found to have increased in the last five years. This suggests that, in recent years, due to the intensified variation in domestic production, vegetable prices have fluctuated more significantly.

Our results are expected to provide evidential support for the government to formulate policies to stabilize vegetable prices and provide a reference for adjusting the content of existing policies. The following policy recommendations can be drawn in light of our findings. First, in stabilizing vegetable prices, it is relatively efficient to formulate supply-side policies. In specific, it is suggested to formulate a manual on yield and production area to monitor and regulate production accordingly. Second, since there are differences in the characteristics of different vegetables, and the contributions of the influencing factors of price fluctuations are also different, different production management is required for different vegetables. Especially for crops with obvious seasonal characteristics like cabbage and radish, corresponding policies must be formulated according to the type. Third, it would be more effective to implement parallel measures of import and supply management for dried red pepper to stabilize its prices, since its price fluctuations are greatly affected by import variation.

Author Contributions: Conceptualization, Y.Q.; methodology, Y.Q. and B.-i.A.; formal analysis, Y.Q.; resources, M.K.; writing—original draft preparation, Y.Q. and M.K.; writing—review and editing, Y.Q. and M.K.; supervision, B.-i.A.; project administration, B.-i.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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Economic Value, Farmers Perception, and Strategic Development of Sorghum in Central Java and Yogyakarta, Indonesia

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Abstract: Sorghum is an important food crop commodity in the midst of climate change conditions and the threat of a global food crisis. Sorghum, which has an adaptive advantage to all land conditions, is suitable for use as a food substitute for rice and wheat. The purpose of this study was to evaluate the economic value, farmers' perceptions, and specific strategies for developing sorghum in Central Java and Yogyakarta, Indonesia. The research was conducted in Wonogiri Regency, Central Java, and Gunungkidul Regency, Yogyakarta from September to November 2022. The research was carried out through the observation of 120 respondents with indicators of farming characteristics and farmers' perceptions of sorghum development, as well as focus group discussions (FGD) and depth interviews with indicators of internal and external factors for sorghum development. The analysis used is benefit cost (BC) to evaluate the economic value of sorghum farming, the Likert scale to determine farmers' perceptions of sorghum, and Strength Weak Opportunity Threat (SWOT) to determine specific strategies for developing sorghum. The results showed that sorghum farming is feasible to develop in Wonogiri Central Java and Gunungkidul Yogyakarta because it provides a profit value greater than production costs with a BCR value of >1. The perception of farmers in Central Java regarding the development of sorghum is included in the very good category with an average value of 3.31, and the perception of farmers in Yogyakarta is included in the good category with an average value of 2.55. The operational policy strategy for developing sorghum in Wonogiri Central Java and Gunungkidul Yogyakarta is an expansion strategy (S-O).

Keywords: sorghum development; farm household economic; economic value; farmer perception; strategic policy

Citation: Widodo, S.; Triastono, J.; Sahara, D.; Pustika, A.B.; Kristamtini; Purwaningsih, H.; Arianti, F.D.; Praptana, R.H.; Romdon, A.S.; Sutardi; et al. Economic Value, Farmers Perception, and Strategic Development of Sorghum in Central Java and Yogyakarta, Indonesia. *Agriculture* **2023**, *13*, 516. https://doi.org/10.3390/agriculture13030516

Academic Editors: Hung-Hao Chang, Pei-An Liao and Jiun-Hao Wang

Received: 2 January 2023
Revised: 10 February 2023
Accepted: 15 February 2023
Published: 21 February 2023

1. Introduction

Sorghum (*Sorghum bicolor* L. Moench) is a staple food for people around the world who live in semi-arid and subtropical countries in Asia and Africa [1]. Sorghum has anti-inflammatory and cholesterol-lowering properties so the consumption of sorghum as a food ingredient is increasing in high-income countries [2]. The high content of bioactive compounds in sorghum seeds and widespread public acceptance of sorghum as a breakfast cereal, beverage, and other products indicates a higher potential for sorghum consumption in the future in several countries such as the United States [3], Brazil [4], South Africa [5], and Kenya [6].

Sorghum has quite good market opportunities for the feed industry, alcohol refining, and flour; even now sorghum processing interventions create business opportunities for the food industry [7]. The prospects for the sorghum market are very promising by expanding the beverage industry, as well as creating jobs and markets for sorghum producers [8]. Sorghum has a high nutritional content so sorghum can replace rice as a food ingredient [9]. In Indonesia, sorghum is the third cereal food crop after rice and corn, but the use of sorghum as food has declined sharply after the availability of sufficient rice at a low price. In Indonesia, the development of sorghum was only seen in the 1940s as a source of food during the famine season. The sorghum planting area in 1990 reached 18,000 ha and was spread over the Demak and Wonogiri areas of Central Java, South Sulawesi, and East Nusa Tenggara. In 2020, the development of 5000 ha of sorghum occurred in East Nusa Tenggara, Yogyakarta, Southeast Sulawesi, and South Sulawesi [10]. Sorghum is a food source containing 332 calories, 73.0 g carbohydrates, 11.0 g protein, 3.3 g fat, 28 mg calcium, 287 mg phosphorus, 4.4 mg iron, and 0.38 mg vitamin B1 [11], so sorghum is feasible to be developed as an alternative food ingredient to replace rice.

Sorghum is a cereal crop that has great potential to be developed commercially because it has broad agro-ecological adaptability, high productivity, is relatively resistant to pests and diseases, does not require large inputs in cultivation, and is more tolerant of marginal conditions [12]. Sorghum, as a drought-tolerant crop that grows well on marginal lands, is a very important commodity that can serve as an alternative food and source of income for smallholder farmers [13]. The development of sorghum is still very slow because the popularity of sorghum is below that of maize [14]. At the farm level, sorghum is grown as an intercrop, a diversion crop for birds [11], and a side crop planted on the edge of the bunds without cultivation techniques so that productivity is still low [15].

Under conditions of global climate change, sorghum has the opportunity to become an important commodity as a food and industrial crop [16,17]. The Russo-Ukraine war affected the production countries to restrict wheat exports in order to prevent the food crisis, so the wheat-importing countries tried to optimize the local commodity resources that could replace the function of wheat. The Indonesian government has formulated a national sorghum development plan for 2022–2024 to increase production and downstream sorghum as a substitute for wheat to safeguard national food security from the threat of the global food crisis. Government efforts and policies are not sufficient only by doubling the area planted and increasing the productivity of sorghum, but also by creating markets and ensuring the level of absorption of sorghum in both domestic and foreign markets. In the road map for the national sorghum development program, it is scheduled that sorghum will be developed in 17 provinces with a target of 30,000 ha (2023) and 40,000 ha (2024) with a production target of 115,848 t (2023) and 154,464 t (2024) assuming productivity of 4.0 t ha^{-1} [18].

Sorghum can be developed in all agricultural land agroecology in Indonesia. The extensification of sorghum cultivation on marginal land is the best alternative to increase the availability of carbohydrate sources. Sorghum plants can produce well on marginal land, so they do not reduce the area planted for rice and corn. In Indonesia, there are still around 60 million hectares of marginal land that have not been cultivated. Increasing sorghum production on marginal land is the most likely solution to reduce wheat imports [19]. Central Java and Yogyakarta have the potential for dry land which is distributed in several districts. Agricultural land in Wonogiri Regency, Central Java, which is dominated by dry land and rainfed paddy fields, has been partially utilized for the development of sorghum. In 2021, Wonogiri Regency will become one of the locations for the 50 ha sorghum development program from the Indonesian Ministry of Agriculture [20]. In Gunungkidul Regency, Yogyakarta, 90% of agricultural land is dry land [21], and sorghum has been developed in several areas. However, the development of sorghum in the region has not been managed upstream and downstream using the latest technology and business institutional governance has not been formed involving farmers, the government, and the private sector. Each area of sorghum development has different agroecological and

socioeconomic resources, so a different strategy is needed for developing sorghum in a region. This study aimed to evaluate the economic value, farmer perceptions, and specific strategies for developing sorghum in Central Java and Yogyakarta. The novelty value of this research is the area-specific strategy for developing sorghum based on the potential strength of regional resources, economic value, and farmers' perceptions as material for policy formulation for a large-scale sorghum development program.

2. Materials and Methods

2.1. Research Site

The research was conducted in Central Java (Wuryantoro and Pracimantoro Sub-Districts, Wonogiri Regency) and Yogyakarta (Wonosari and Karangmojo Sub-Districts, Gunungkidul Regency) from September to November 2022. The selection of the research location was carried out deliberately with the consideration that the location is a sorghum production center [22,23] and a target area for Indonesia's national sorghum development program for 2022–2024. Agricultural land in Wonogiri Regency is rainfed dry land and tides. In general, farmers own more than one plot of land planted with more than one crop commodity. Farmers cultivate crops in monoculture and intercropping. Working in the agricultural sector is very important because most of the family income comes from the agricultural sector [24]. Most of Gunungkidul is rainfed dry land which is very dependent on climate cycles and is the main food barn for the community. In general, farmers plant food crops twice a year. The choice of cropping pattern is a consideration for farmers in allocating labor because farmers work outside agriculture during the dry season to meet food and non-food needs. Farmer household behavior will allocate the income earned for food and non-food consumption needs so that they maximize their business with all the limitations they have [25]. Map of research activity locations in Central Java and Yogyakarta are presented in Figures 1 and 2.

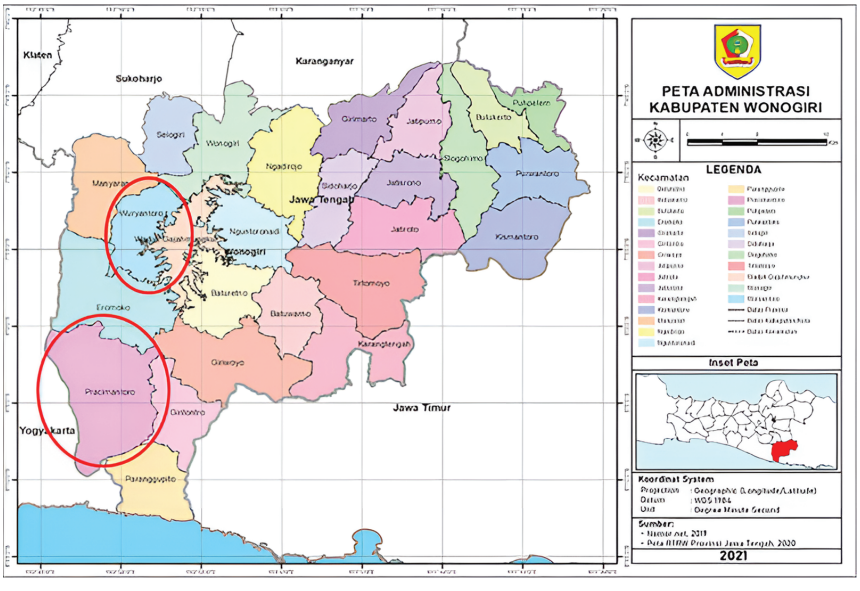

Figure 1. Wuryantoro and Pracimantoro Sud-District, Wonogiri Regency, Central Java. (Data from: Ahmad [26]).

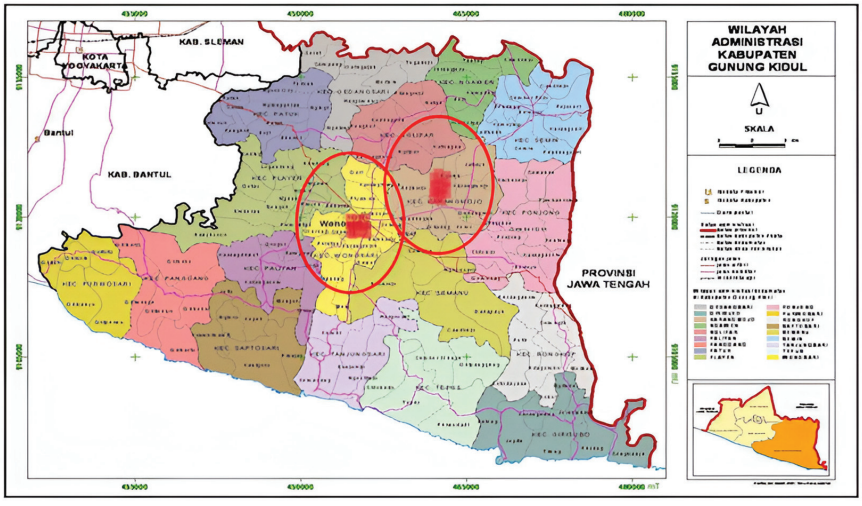

Figure 2. Wonosari and Karangmojo Sub-District, Gunungkidul Regency, Yogyakarta. (Data from: Peta Kota [27]).

2.2. Sampling Design

This study uses a cross-sectional survey design that collects data at a single point in time. The sampling of farmers was carried out in two stages; the first stage was selecting farmers in areas that were sorghum production centers, and the second stage was identifying farmers who planted sorghum in monoculture.

2.3. Data Collection

Primary data was collected using a survey method of 120 farmers who grow sorghum in selected locations (70 farmers in Central Java and 50 farmers in Yogyakarta) and FGD methods with farmers, traders, private actors (off-takers), and policyholders at the provincial/district level and home industry with a total 40 participants. The selection of respondents was carried out purposively, namely farmers who had cultivated sorghum in monoculture and obtained 70 respondents in Central Java and 50 respondents in Yogyakarta. The number of respondents in the two locations met the criteria for the number of respondents for survey research [28]. Each FGD participant conveyed information according to their field related to sorghum development: policyholder (support and sorghum development program); farmers (experiences, problems, and future hopes in developing sorghum); traders (market opportunities and purchasing capacity); off-takers (marketing, pricing, distribution, partnerships); and home industry (types of processed sorghum).

Primary data collection through interviews with farmers and traders who were selected as respondents using a list of questions. Primary data collected include the following: characteristics of sorghum farming; farmers' perceptions of sorghum development; as well as internal and external factors of the potential for sorghum development in Central Java and Yogyakarta which were collected through FGDs. Two topic sets were used in the interviews, namely the topic set to find out farmers' perceptions of sorghum development and the topic set about the financial feasibility of sorghum farming. The topic set for farmers' perceptions includes 11 indicators, namely the ease of obtaining sorghum seeds, seed growth, plant growth, plant maintenance, resistance to pests and diseases, sorghum production, sorghum market, sorghum marketing, sorghum seed processing, sorghum prices, and profits from sorghum farming. Topics set for financial feasibility include quantity and price of seeds, fertilizers, and pesticides, wages for labor, land tax, depreciation of agricultural equipment, production, and price of sorghum.

Secondary data were obtained from the Central Bureau of Statistics of Central Java and Yogyakarta Provinces, as well as some of the results of previous studies as listed in the Bibliography. Secondary data is used as information to support and discuss research results.

2.4. Data Analysis

2.4.1. Economic Value of Sorghum Farming

Evaluation of the economic value of sorghum developed by farmers in Central Java and Yogyakarta was analyzed by using the B/C approach of Yang et al. [29], as follows:

$$\pi_i = TR_i - TC_i \text{ and } B/C_i = \pi_i / TC_i$$

Description:

Π_i = Farming profits *i*-th
TR_i = Total farming revenue *i*-th
TC_i = Total farming cost *i*-th
B/C_i = Farming feasibility *i*-th

If the BCR value is 1.0, then farmers will benefit from sorghum farming, so they can continue sorghum development, whereas if the BCR value is <1.0, farmers will not benefit from sorghum farming and farming does not need to be continued [30].

2.4.2. Farmers' Perceptions of Sorghum Development

Data on farmers' perceptions of sorghum development in the form of ordinal data were analyzed using a scoring technique [31]. Farmers' perceptions were assessed using a Likert scale with a score of 1–4 in the very good, good, bad, and very bad categories. Furthermore, the perception data were analyzed using scoring with the formulation of Milkias et al. [32], as follows:

$$Nilai\ skore = \frac{n_i.s_i}{N_i}$$

Description:

n_i = The number of respondents in the column *i*-th (i = 1, 2, 3)
s_i = Statement score *i*-th (i = 1, 2, 3)
N_i = The number of respondents on the row *i*-th (i = 1, 2, 3)

If the criterion value is between 1.00–1.75 = very bad perception category, 1.76–2.50 = bad perception category, 2.51–3.25 = good perception category, and 3.26–4.00 = very good perception category [32].

Farmers' perceptions of sorghum development are categorized by 3 class interval scales, namely high, medium, and low. The interval scale is determined by the following formula:

$$Interval\ Scale = \frac{The\ highest\ score - The\ lowest\ score}{Number\ of\ interval\ scale}\Big)$$

The diversity of farmer perceptions of sorghum development is visualized using the Perceptual Mapping technique which describes the relationship between farmer perceptions and predetermined attributes [33].

2.4.3. Strategic Development of Sorghum

Specific strategies for developing sorghum in Central Java and Yogyakarta were determined through a SWOT analysis. SWOT analysis begins with identifying the strengths (S) and weaknesses (W) in sorghum development, as well as opportunities (O) and threats (T) from the external environment that can maximize S and minimize W and T in sorghum development [34]. All of these factors were tabulated into the internal factor evaluation matrix (IFEM) and the external factor evaluation matrix (EFEM) and then given a weight rating and score for each factor's S, W, O, and T [35].

The SWOT analysis steps are as follows by LAN [36]:

- Identify internal factors in the form of S and W and external factors in the form of O and T.
- Determine the three priority factors of S, W, O, and T. The three priority factors of S, W, O, and T were determined based on the ranking of the choices of the FGD participants (40 people) with the following criteria: (1) the first priority is >50% of the participants; (2) second priority choice of 25–50% of participants; and (3) the third priority for <25% participants.
- Priority internal and external factors are then analyzed to determine the magnitude of the Urgency Value (UV). UV is the basis for determining the Factor Weight (FW) of each internal and external factor. UV value is determined by comparing the level of importance of one factor with other factors in the group of internal/external factors. UV ranges from 1 to 5 with the provision that the higher the UV value means the level of importance between one factor and another is very high and vice versa. BF is calculated by dividing the number of UV from each factor by the total value of the internal/external factor group and multiplied by 100.
- Determining the Key Success Factors (KSF) through evaluating internal and external factor linkages to determine the Support Value (SV) and the Support Weight Value (SWV), as well as the Average Linkage Value (ALV), the Linkage Weight Value (LWV) and the Total Weight Value (TWV) of each factor. The SV value is between 1 and 5 and the higher the SV value, the higher the support from that factor. The value of relatedness (VR) is determined by giving a score of 1 (very little relatedness) to 5 (very high relatedness). Key Success Factors is selected from the largest TWV from each of the factors of S, W, O, and T. Calculation of each factor analysis is as follows:

  $SWV = FW \times SV$
  $ALV = \text{Total } VR/n-1$
  $LWV = ALV \times FW$
  $TWV = LWV + SWV$

- Determine the strength map based on the results of the evaluation of the interrelationships of internal and external factors. The strength map is obtained by comparing the TWV from all S values with all W values and the TWV from all O values with all T values.
- Formulation of operational policy strategies using the SWOT strategy formulation. The four main strategies that can be formulated in the four SWOT quadrants are presented in Table 1:
- Preparation of activity plans by outlining each operational policy strategy in the form of activity plans that need to be implemented.

Table 1. SWOT strategy formulation.

Quadrants	Strategy	Description
1	Expansion Strategy (S-O)	Strategies use S to seize O
2	Diversification Strategy (S-T)	Strategies use S to overcome or minimize T
3	Stability or Rationalization Strategy (W-O)	Strategies to overcome W by taking advantage of O
4	Defensive or Survival Strategy (W-T)	The strategy of fixing W by minimizing T

3. Results

3.1. Economic Value of Sorghum Farming

The production inputs used in sorghum farming in Central Java and Yogyakarta are relatively the same including seeds, fertilizers, pesticides, labor, and other fixed costs. Farmers in Wonogiri Regency used the red sorghum variety (Suri 3) with a seed amount of 13 kg ha^{-1}, and farmers in Yogyakarta used white sorghum (PB) and local red sorghum varieties with a seed amount of 10 kg ha^{-1}. The fertilizers used were urea, ZA, Phonska, and

different amounts of manure at the two locations, except that ZA was not used in Central Java. The total cost of sorghum production consists of variable costs (seeds, fertilizers, pesticides, and labor) and fixed costs (land tax and depreciation value of equipment), amounting to USD 382.08 and USD 672.68, respectively. The highest costs used in both locations were labor costs, which were USD 293.61 and USD 471.71 respectively. The sorghum production obtained in Central Java was USD 0,19 kg ha^{-1} with a value of USD 808.64, whereas sorghum production in Yogyakarta was 5750 kg ha^{-1} with a value of USD 1549.90. Analysis of the economic value of sorghum farming in Central Java and Yogyakarta is presented in Table 2.

Table 2. Economic value of sorghum farming in Wonogiri Central Java and Gunungkidul Yogyakarta, 2022.

Types of Production Input	Central Java		Yogyakarta	
	Physical (ha^{-1})	**USD (ha^{-1})**	**Physical (ha^{-1})**	**USD (ha^{-1})**
Variable Cost:				
a. Seed (kg)	13	3.23	10	3.85
b. Fertilizer (kg)				
• Urea	110	16.94	150	23.10
• ZA	-		230	36.90
• Phonska	110	17.65	280	50.32
• Manure	870	19.51	2250	50.54
c. Pesticides (package)		12.84		21.82
d. Labor (man days)	65	293.61	90	471.71
Total Variable Cost		363.79		654.39
Fixed Cost				
a. Land Tax		7.06		7.06
b. Equipment Depreciation Costs		11.23		11.23
Total Fixed Cost		18.29		18.29
Total Farming Cost		**382.08**		**672.68**
Production (kg)	3.000	808.64	5750	1549.90
Benefits		436.10		877.22
BCR		1.14		1.30

Noted: Source = Primary Data 2022 (processed); 1 USD = 15,581.65 IDR (23 December 2022).

3.2. Farmers' Perceptions

The survey results show that 63.64% of farmers in Central Java have a very good perception and 36.36% of farmers have a good perception of the 11 indicators of sorghum development. Meanwhile, of farmers in Yogyakarta, as much as 54.55% have a good perception, 36.36% not good, and 9.09% very bad. Overall, the perception of farmers in Central Java towards the development of sorghum is included in the very good criteria with an average value of 3.31, and the perception of farmers in Yogyakarta is included in the good category with an average value of 2.55. Farmers' perceptions of the sorghum price indicator in Yogyakarta are very unfavorable. Farmers' perceptions of sorghum development in Central Java and Yogyakarta is presented in Figure 3.

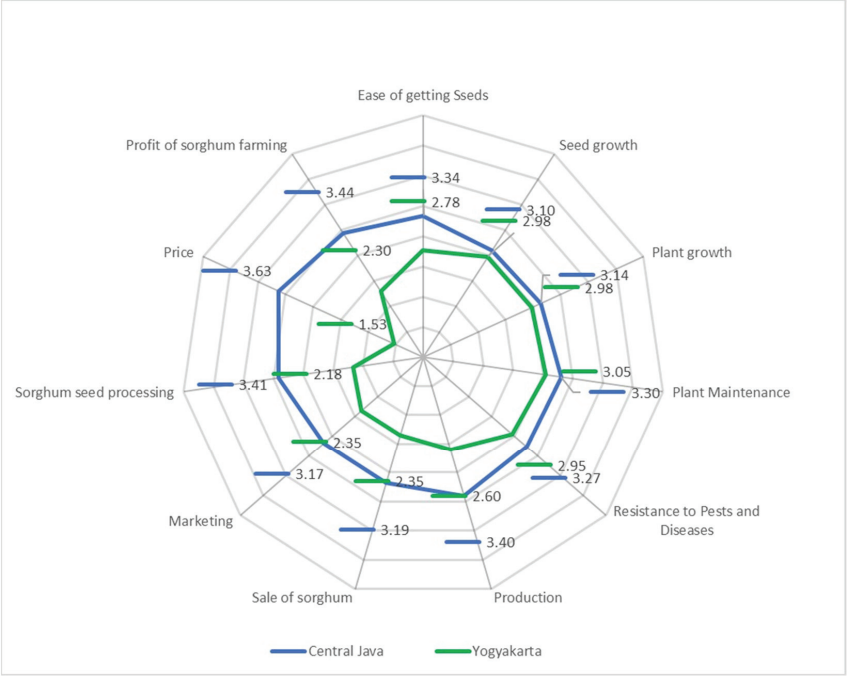

Figure 3. Farmers' perceptions of sorghum development in Central Java and Yogyakarta, 2022. Source = Primary Data 2022 (processed).

3.3. Strategic Development of Sorghum

3.3.1. Internal, External, and Priority Key Factors

Through FGD, internal factors (S and W) and external factors (O and T) which are priority factors in sorghum development in Central Java and Yogyakarta have been identified. Inside the internal factors, there are two factors that are the same as S for sorghum development in Central Java and Yogyakarta, namely agro-climatic and land availability, although they differ in the priority ranking. Likewise, with W, there are also two common factors, namely cultivation technology that is not yet intensive and prices that are not yet stable. Meanwhile, in terms of external factors, the high demand for sorghum is an O in both regions. All the factors that pose a T to sorghum development in the two regions are the same, namely pest attacks, land competition, and climate anomalies. The identification results of three priority internal factors and three priority external factors for sorghum development in Central Java and Yogyakarta are presented in Tables 3 and 4.

The results of the KSF evaluation of sorghum development in Central Java showed that the S factor was a favorable agro-climatic (BNP = 1.42); the W factor is the unstable price (TWV = 0.63); the O factor is the high demand for sorghum processed products and products (TWV = 0.93); and the T factor is pest attack (TWV = 0.41). Meanwhile, the results of the KSF evaluation for sorghum development in Yogyakarta showed that the S factors are as follows: land potential in the third planting season and unused land (BNP = 2.18); cultivation is not yet intensive/traditional (BNP = 1.55); market demand is high, and prices are starting to improve (TWV = 2.25); and the T factor is competitive land use (BNP = 0.87). The results of evaluating internal and external factors on sorghum development in Wonogiri Central Java and Gunungkidul Yogyakarta are presented in Tables 5 and 6.

Table 3. Priority factors of SWOT to sorghum development in Wonogiri Central Java, 2022.

Priority	S	W	O	T
1	Agro-climatic supports (60%)	Unstable prices (55%)	Demand for sorghum processed products and products is high (60%)	Pest attack (62.5%)
2	Low input/low production costs (25%)	Cultivation and processing technology has not been mastered (27.5%)	Utilization of waste/biomass has a high added value (30%)	Competitive in land use especially with corn commodity (25%)
3	Available land that can be utilized in the third growing season (15%)	There is no pre and post-harvest mechanization available (17.5%)	There is no sorghum seed cultivator yet (10%)	Climate anomaly, if during the third growing season (on season) it rains a lot, farmers plant other commodities (12.5%)

Noted: Source = Primary Data 2022 (processed); Numbers in brackets indicate the percentage of FGD participants who chose priority factors.

Table 4. Priority factors of SWOT to sorghum development in Gunungkidul Yogyakarta, 2022.

Priority	S	W	O	T
1	Land potential in the third growing season and unused land (52.5%)	Cultivation is not yet intensive/traditional (55%)	Market demand is high, and prices are starting to improve (62.5%)	Climate anomaly/seasonal shift (65%)
2	Human resources are available and it is customary to grow sorghum (27.5%)	Productivity of sorghum seeds is still low, more dominant for animal feed (25%)	There began to be off-takers/exporters specifically for certain/local red sorghum varieties (27.5%)	Pests (birds, whitefly, long-tailed monkeys, rats) (25%)
3	Land suitability and climate support (appropriate agro-ecosystem) (20%)	Prices for dry beans are still low (20%)	Local food diversification: rice, flour, tempeh, and sorghum added value is starting to improve (10%)	Competitive land use (10%)

Noted: Source = Primary Data 2022 (processed); Numbers in brackets indicate the percentage of FGD participants who chose priority factors.

Table 5. Evaluation of internal and external factors in sorghum development in Wonogiri Central Java, 2022.

Internal and External Factors	FW (%)	SV	SWV	ALV	LWV	TWV	KSF
S						**2.14**	
Agro-climatic supports	26.67	5	1.33	4.00	1.07	1.42	1
Low input/low production costs	20.00	5	1.00	3.27	0.65	0.65	2
Available land can be utilized in the third growing season	6.67	5	0.33	2.82	0.19	0.06	3
W						**1.02**	
Unstable prices	20.00	4	0.80	3.91	0.78	0.63	1
Cultivation and processing technology has not been mastered	20.00	3	0.60	3.00	0.60	0.36	2
There is no pre- and post-harvest mechanization available	6.67	3	0.20	2.36	0.16	0.03	3
O						**1.46**	
Demand for sorghum processed products and products is high	26.67	4	1.07	3.27	0.87	0.93	1
Utilization of waste/biomass has a high added value	13.33	5	0.67	3.36	0.45	0.30	2
There is no sorghum seed cultivator yet	13.33	4	0.53	3.27	0.44	0.23	3
T						**0.52**	
Pest attack	26.67	2	0.80	2.91	0.78	0.41	1
Competitive land use especially with maize	13.13	2	0.27	2.91	0.39	0.10	2
Climatic anomaly, if during the third growing season (on season) it rains a lot, farmers plant other commodities	6.67	1	0.07	1.55	0.10	0.01	3

Noted: Source = Primary Data 2022 (processed).

Table 6. Evaluation of internal and external factors in sorghum development in Gunungkidul Yogyakarta, 2022.

Internal and External Factors	FW (%)	SV	SWV	ALV	LWV	TWV	KSF
S						**5.01**	
Land potential in the third growing season and the land has not been utilized	26.67	5	1.33	3.18	0.85	2.18	1
Farmers' resources are available and they usually grow sorghum	20.00	5	1.00	3.55	0.71	1.71	2
Land suitability and supportive climate (agro-ecosystem)	13.33	5	0.67	3.36	0.45	1.12	3
W						**3.33**	
Cultivation is not yet intensive/traditional	20.00	4	0.80	3.73	0.75	1.55	1
Productivity is still low, dominant for animal feed	13.33	5	0.67	3.09	0.41	1.08	2
Prices for dry beans are still low	13.33	3	0.40	2.27	0.30	0.70	3
O						**4.48**	
Market demand is high, and prices are starting to improve	26.67	5	1.33	3.45	0.92	2.25	1
Start there off-taker/exporter red local variety and new superior varieties	20.00	3	0.60	3.36	0.67	1.27	2
Local food diversification: rice, flour, sorghum tempeh	13.33	4	0.53	3.18	0.42	0.96	3
T						**2.06**	
Competitive land use	13.33	3	0.40	3.55	0.47	0.87	1
Climate anomaly/seasonal shift	13.33	2	0.27	3.00	0.40	0.67	2
Pests (birds, whitefly, long-tailed monkeys, rats)	13.33	2	0.27	1.91	0.25	0.52	3

Noted: Source = Primary Data 2022 (processed).

3.3.2. The Strength Maps

The results of evaluating the relationship between internal and external factors in the development of sorghum in Central Java show that the position of the strength map is as follows: S of 2.14; W of 1.02; O of 1.46; and T of 0.52. After the TWV value of all S values is reduced by all W values, a value of 1.12 is obtained, and the TWV value of all O values is reduced by all T values, which is 0.94. Meanwhile, the position of the strength map of sorghum development in Yogyakarta is S of 5.01; W of 3.33; O of 4.48; and T of 2.06. The TWV value of S minus W is 1.68, and the value of TWV O minus T is 2.42. The strength map of sorghum development in both Central Java and Yogyakarta is in quadrant I or S-O with the proportion of S being greater than O. The priority strategy for developing sorghum is an expansion strategy (S-O), namely a strategy to utilize S to seize O. A strength map of sorghum development in Wonogiri Central Java is presented in Figure 4, whereas a strength map of sorghum development in Gunungkidul Yogyakarta is presented in Figure 5.

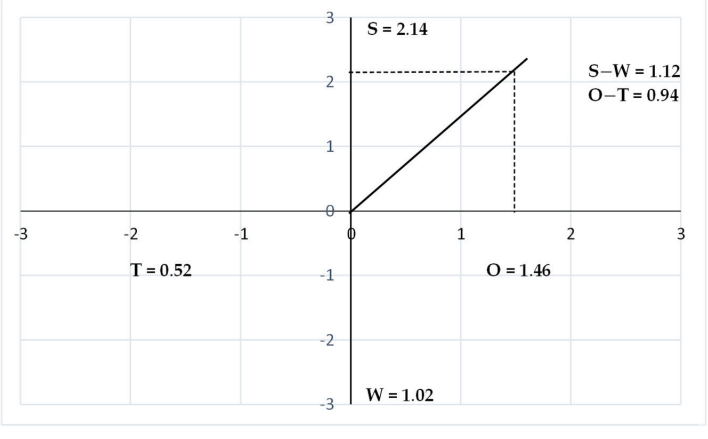

Figure 4. Map of the strength of sorghum development in Wonogiri Central Java, 2022.

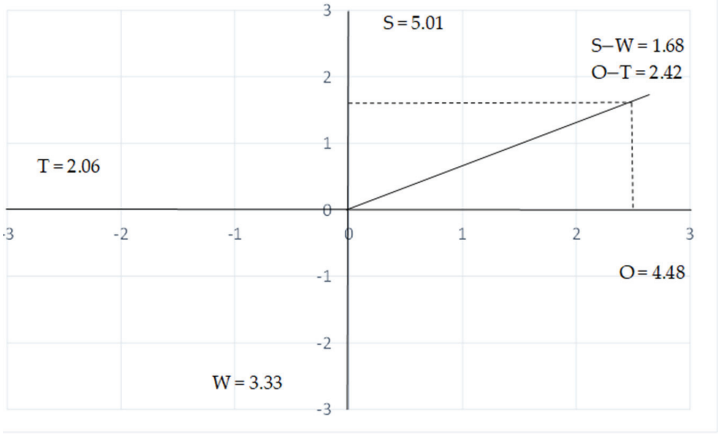

Figure 5. Map of the strength of sorghum development in Gunungkidul Yogyakarta, 2022.

4. Discussion

4.1. Economic Value of Sorghum Farming

Farmers in Wonogiri use more seeds than farmers in Yogyakarta, even though the amount of seed used is in accordance with the seed requirements for sorghum production, namely 10–15 kg ha^{-1}. The use of more seeds in Central Java is due to a distance planting, namely 20 cm × 60 cm or 40 cm × 40 cm, whereas the distance planting used in Yogyakarta is 30 cm × 50 cm or 40 cm × 70 cm. The closer the distance planting and the greater the number of seeds per hole, the more seeds are needed. The use of fertilizers in the two locations is still not according to the recommendations, but is performed according to the habits and capital capabilities of the farmers. Farmers with low incomes are unable to use fertilizer according to plant needs [37]. Sorghum farmers in Nigeria use fertilizers under recommendations because the availability of government-subsidized fertilizers is not easily accessible [38].

The variable cost of sorghum production in both locations ranged from 95.21–97.73% of the total production cost, and the highest cost was used to pay for labor, which was 70.12–76.85% of the total production cost. This is in line with the labor cost for sorghum production in India which is 42.46% [39] and 54% of the total production cost [40], whereas other costs have a lower proportion. The lower number of workers used in Central Java indicates a farming system that is not yet intensive, characterized by minimum tillage without even tillage, and rarely monitoring seed germination after planting. The use of labor in Yogyakarta is equivalent to the use of labor in sorghum farming in India, an average of 84.64 man-days [39].

The profits received by farmers in Yogyakarta are higher than those received by farmers in Central Java. Based on the BCR value >1, sorghum farming in both locations is feasible to develop because it provides a profit value greater than production costs. This value is higher than the BCR value of sorghum farming in Sinai Peninsula, Egypt of 0.65 [41], and Nigeria of 0.91 [42]. This indicates that farmers benefit from sorghum farming with varying values due to differences in the amount and cost of production.

4.2. Farmers' Perceptions

In general, farmers in Central Java have a better perception of sorghum development than farmers in Yogyakarta. A stark contrast can be seen in the Yogyakarta farmers' perception of the price of sorghum which is not very good (1.53). Farmers in Yogyakarta have experienced very unfavorable sorghum prices between USD 0.06–0.11 kg^{-1}, whereas farmers in Central Java have very good perceptions of sorghum prices because farmers have obtained sorghum prices between USD 0.20–0.32 kg^{-1}. Even so, until now the price

of sorghum is still unstable and the government has not set a price for sorghum in the same way as other food (rice) prices. The perception of farmers in Yogyakarta with unfavorable criteria can also be seen in the indicators of sorghum processing (2.18), profits (2.30), sales, and marketing of sorghum, each indicator having a value of 2.35. The unfavorable criteria for the four indicators are due to the absence of sorghum seed processing facilities and market access which is still difficult so farmers are worried that production will not be absorbed.

Farmers have good perceptions of cultivation techniques because farmers easily obtain seeds, grow seeds and plants easily and quickly, are relatively resistant to pests and diseases, have high crop production, and can be harvested more than once and provide benefits. Mukin et al. [43] state that the sorghum cultivation technique is very easy for farmers to do and harvesting sorghum can be completed two to three times a season.

In contrast to farmers in Yogyakarta, farmers in Central Java have good perceptions of indicators of seed growth, plant growth, sales, and marketing of sorghum, whereas very good perceptions are obtained on indicators of ease of obtaining seeds, cultivation techniques, sorghum processing, price, and profit. Farmers in several areas also have good perceptions of sorghum cultivation techniques. Farmers in Bantul Regency show a good perception of the development of sorghum plants through cultivation innovation and utilization of sorghum [44]. Farmers in East Wellega and West Shewa in Oromia State, Ethiopia showed a good perception of sorghum crops that have a tolerance to bird attacks [45]. Farmers in Lembata Regency have a very good perception of the development of sorghum farming [46].

Sales and marketing of sorghum in Central Java are perceived as very good because there are sorghum markets or traders so farmers have no difficulty selling sorghum seeds. Sales of sorghum is an indicator that is very important to less important depending on different ethnic groups [47]. Likewise, the price of sorghum and the benefits obtained are perceived very well by farmers because the average price of sorghum is USD 0.27 kg^{-1} which is almost equivalent to the price of harvested dry grain. If rice is the main crop cultivated by farmers, sorghum is a secondary crop grown by farmers with less intensive business, so if the price of sorghum seeds is close to the price of grain, farmers will respond positively. High sales of sorghum will affect the amount of profit farmers receive. Nevertheless, farmers hope that the government can maintain sorghum price stability and market certainty to accommodate the sorghum produced by farmers.

4.3. Strategic Development of Sorghum

4.3.1. Priority Internal Factors for Sorghum Development

Strength

a. Agro-climatic conditions

The agro-climatic conditions in the Wuryantoro and Pracimantoro sub-districts of Wonogiri support the growth of sorghum plants [47]. Sorghum has been grown by the local community for generations on a small scale using conventional cultivation techniques until the last two years it began to be developed intensively in paddy fields and dry land. The agro-climatic conditions in the Karangmojo and Wonosari sub-district of Gunungkidul are also suitable for the growth of sorghum plants. The sub-districts of Semin, Ponjong, Rongkop, Semanu, Tepus, and Girisubo have potential criteria for growing sorghum [48].

The environment plays an important role in sorghum production [49]. Agroecological conditions are a prerequisite for increasing sorghum production in irrigated land in the Republic of Mexico [50]. Sorghum plants can grow well at temperatures of 23–30 °C, and relative humidity of 20–40% with altitudes above 500 m asl. Sorghum can grow well in almost all types of soil with a pH ranging from 5.0 to 7.5 [51]. The research results of Juniarti et al. [52] showed that land in Padang Laweh District, Sijunjung Regency, West Sumatra has the potential for the development of sorghum plants with characteristics of an average temperature of 25–27 °C, rainfall <200 mm, humidity <75%, good drainage, soil depth >60 cm, pH 4.4–6.1, and low availability of nutrients N, P, and K. Soil characteristics,

climate, and topography are the main criteria used to determine land suitability for sorghum cultivation in the Agamsa sub-catchment of Northeast Ethiopia [53]. The main factors affecting the suitability of land for growing sorghum in the Jinsha River basin are the slope of the terrain, the height, and the thickness of the soil layer. Factors such as soil texture, the certainty of water sources, and drainage conditions also have an impact on land suitability for sorghum crops [54].

b. Low production costs

The low cost of production inputs is the reason for farmers in Wonogiri to plant sorghum in the third growing season, both on rainfed and dry land. Adaptability is quite good on dry land and grows well with minimal input, causing sorghum to grow widely. Due to its high production potential and low input use, sorghum is cultivated in tropical, subtropical, and temperate regions of the warmer semi-arid regions of the world [1]. Tesema [55] states that the main inputs for sorghum production are seeds, soil, and fertilizer. Sorghum production can be increased by 26% without increasing the input of land area and labor allocation, even input costs can be reduced by 56% without changing production levels [56].

c. Availability of land

The availability of land in the Wuryantoro and Pracimantoro Wonogiri sub-districts is quite large for sorghum development, both intensive paddy fields and dry land. The availability of land in the Gunungkidul area is considered quite extensive, especially in dry land or rainfed paddy fields. During the third planting season from May/June to August/September, there is still a lot of unused land and only part of the land is used for planting sorghum or other crops.

Soil physical and chemical characteristics are the most important parameters in determining land suitability for sorghum development among parameters of climate, topography, and land erosion rate [57]. Al-Mashreki et al. [58] used an overlay technique to determine land suitability for sorghum development based on scoring four agro-climatic factors, namely soil, climate, erosion level, and topography. Based on the physical and chemical analysis of the soil, land suitability classes can be distinguished into two classes, namely actual and potential land for the development of sorghum crops [59]. Actual land means that the physical and chemical properties of the soil are suitable for optimal growth of sorghum plants, whereas on potential land there are still limiting factors that can still be improved [60]. Potential land can be improved by adding organic matter, NPK fertilizer, terracing, planting cover crops, and drying [61]. Suitable land for the development of sorghum in the Wuryantoro Wonogiri District area includes Wuryantoro, Genukharjo, Gumiwanglor, Mlopoharjo, Pulutankulon, Pulutanwetan, Mojopuro, and Sumberejo [47]. Potential land suitable for sorghum development in Gunungkidul is evenly distributed in the sub-districts of Wonosari, Karangmojo, Ponjong, Tepus, and Girisoba; even in the Wonosari and Karangmojo sub-districts, there is 8898 ha of land that can be used for sorghum development. This is supported by cattle and goat livestock centers which require animal feed from sorghum waste.

d. Human resources are available and it is customary to grow sorghum

Sorghum has long been cultivated in Gunungkidul and developed in the 1980s, but its utilization is more dominant for animal feed. Utilization of land area, seeds and manure have a positive effect on sorghum production in Gunungkidul [62]. Availability of land and demand for animal feed causes farmers in Gunungkidul to develop sorghum. Sorghum farming contributes 2% to farmers' total income [14]. Farmers gain experience cultivating sorghum from generation to generation, making it easier to accept technological advances to increase production.

Weaknesses

a. Prices are unstable and tend to be low

The price of sorghum in 2022 is considered by farmers to be quite good, between USD 0.26–0.28 kg^{-1}, which was previously only around USD 0.06–0.11 kg^{-1}. The price of dry sorghum seeds tends to be unstable, influenced by the quality and quantity of sorghum seeds. Apart from the quality of sorghum, limited sorghum traders, price guarantee, and the absence of off-takers, farmers consider it more profitable if it is used for animal feed, so farmers grow sorghum only as a border and are not managed intensively. Sapanali et al. [63] state that inappropriate selling prices are a farming risk. Farmers hope that the price of sorghum will be as stable as it is today and that there will be markets and home industries that can absorb the sorghum yields.

b. Farmers have not mastered cultivation and processing technology

In Wonogiri, generally, farmers do not apply intensive cultivation techniques in growing sorghum so the resulting production is not optimal between 2.4–3.0 t ha^{-1}. Farmers also have not processed sorghum into semi-finished products (analog rice or flour) or finished products (various foods or beverages). Sorghum cultivation in Gunungkidul is still traditional because farmers perceive the sorghum business as a side business to fill fallow or intercropping land. Farmers planted sorghum as a border, planted with an intercropping system, without providing fertilizer and without controlling pests and diseases. Farmers also do not maintain ratoons properly, so the productivity of the ratoons is very low and they are only used for animal feed. Increased sorghum production must be supported by technology and capacity building of farmers in the production and post-harvest processes. The added value of processing a commodity can provide better prices for farmers [63,64].

c. There is no pre-harvest and post-harvest mechanization available

The development of sorghum in Wonogiri has not been supported by the availability of agricultural mechanization. In Wuryantoro District, farmers use a rice threshing machine to separate the sorghum seeds from the panicles, whereas in Pracimantoro this is performed manually. Machines for processing sorghum seeds into rice and flour are available outside the region at quite high prices, namely USD 0.95 kg^{-1}. Agricultural machinery plays a major role in farming, especially in times of labor shortages. The use of agricultural mechanization in a fairly wide area provides several benefits in the form of saving time, reducing labor use, reducing costs, increasing productivity, and reducing yield losses [65].

d. The productivity of sorghum seeds is still low

The productivity of sorghum in Gunungkidul is still low, ranging from 1–2 t ha^{-1}, but there is additional income indirectly from utilizing sorghum waste for animal feed. The low productivity of sorghum is because farmers have not utilized technology, especially the use of superior varieties, and plant maintenance is not carried out intensively, even without fertilizer application. Rahman et al. [66] stated that the application of cultivation technology, especially the use of high-yielding sorghum varieties, was able to increase production.

4.3.2. Priority External Factors for Sorghum Development

Opportunities

a. Demand for sorghum processed products and products is high

Sorghum is one of the potential commodities that can be developed to support food and energy diversification programs in Indonesia. Sorghum has good market prospects as an industrial raw material to meet consumer demand for food diversification. the use of sorghum in the industry has a fairly good market opportunity to expand the industry and create jobs [7,8]. Currently, the demand for sorghum seeds is quite high with prices up to USD 0.38 kg^{-1}. The utilization of sorghum seeds is mostly for food, especially rice, flour, bird feed, and mixed animal feed. A number of off-takers have started looking for sorghum raw materials, but not much is known about the sorghum-producing centers.

b. Waste and biomass have added value

The utilization of sorghum plants as animal feed has very open opportunities [67]. Several varieties of sorghum contain nutrients suitable for forages such as Keller and Wray [68]. The Pahat variety of sorghum was able to provide a total biomass yield potential of 26.6 t ha^{-1}, with a crude protein content of 10.95%, 92.23% organic matter, and 58.77% NDF [69]. The relatively large yield potential and high nutrient content can meet the nutritional needs of ruminants, so sorghum can be a source of feed both now and in the future.

c. There is no sorghum seed cultivator available

Seed is the main input in crop production through its physical, physiological, and genetic qualities which affect plant growth and development [70]. Production of quality seeds is an opportunity for farmers to improve the quality of sorghum seeds [71]. Most of the sorghum seeds in Wonogiri come from their own harvest and buy seeds from shops or from government programs because there are no sorghum seed growers.

d. Starting to have off-takers

One of the keys to the development of sorghum is the existence of a partner who guarantees price and production. Farmers will use their land to develop sorghum if there is a market available to accommodate the harvest. The market is the main factor for broadly developing sorghum [9]. Until 2021 there have been no off-takers who have collaborated with sorghum farmers in Gunungkidul. Currently, there are pilot collaborations with local off-takers to utilize local red varieties of sorghum seeds as a food mixture.

e. Local food diversification

In Gunungkidul, sorghum has begun to be processed into sorghum rice, sorghum flour, and several other products such as sorghum snacks and sorghum tempeh. However, several types of processed products are still on a limited scale and are marketed in the Gunungkidul area. The utilization of sorghum in the form of flour is more profitable because it is more practical and easier to process into various snack products. Sorghum flour can be used as a raw material for making various types of snacks. Sorghum flour has a fine texture and the amino acids that make up its protein are able to form gluten better than corn flour, although quantitatively and qualitatively it is lower than wheat flour. Sorghum flour can substitute up to 80% of flour for pastries (cookies), 40–50% for cakes, 30–35% for noodles, and 15–20% for bread and the like without significantly reducing the taste, texture, and aroma [10].

Threats

a. Pest attack

The dominant pests in the development of sorghum in Wonogiri and Gunungkidul are birds. Bird pests are one type of pest that causes the highest crop failure in sorghum plants [72]. This pest can cause up to 100% yield loss if there are no rice or corn crops at harvest. Birds eat sorghum seeds, especially the white ones and the relatively low tannin content [73]. A bird weighing 40–50 g is able to consume 10 g day^{-1} of sorghum seeds [10]. Farmers in Gunungkidul save sorghum panicles using net traps, wrapped in plastic bottles. Some of the things that affect the high rate of bird attacks are the location of the sorghum plants which are close to bird breeding habitats, planting that is not simultaneous, and varieties. Methods of controlling birds include planting simultaneously in large expanses, installing bird scare devices, and environmental sanitation from weeds which are the habitat of birds [74].

b. Competitive land use with corn commodity

Seeing the potential of sorghum which has wide adaptability in various types of land, it is feared that there will be competition for land use with other palm crops such as corn. Generally, sorghum is planted after the rice harvest if it is developed in intensive land. If

the price of sorghum is the same or higher than corn and there is a guaranteed market, farmers will tend to use their land to plant sorghum because it is easier to cultivate and requires lower production inputs.

c. Climate anomaly

Climate anomaly is a shift of the seasons from the normal average. Climate anomalies such as the occurrence of La Nina affect the development of sorghum. Climate shifts caused sorghum cultivation in Gunungkidul to experience obstacles during harvesting and processing. Farmers experienced difficulties in drying during the sorghum harvest in August–September 2022 when it still rained. Another impact is a shift in the planting season and changes in cropping patterns and systems. Climate change causes a shift in the start of the rainy season and dry season which causes a change in the planting season [75]. In Wonogiri, sorghum is generally planted during the third growing season or the dry season. Wet climate conditions make farmers switch to more profitable commodities such as corn, peanuts, or rice. The rice–rice–corn cropping pattern is more profitable than other cropping patterns in a La Nina climate [76]. Changes in rainfall cause a reduction in paddy fields, changes in river and groundwater discharge, decreased productivity, decreased planting area and harvested area, decreased yield quality, decreased cropping index, and increased pest attacks [77].

4.3.3. Sorghum Development Policy Strategy

Based on the power map of sorghum development in Central Java and Yogyakarta, a SWOT strategy formulation can be formulated in the form of a SWOT matrix which is formulated from the four key success factors. The formulation of the SWOT strategy for developing sorghum in Central Java and Yogyakarta is presented in Tables 7 and 8.

Table 7. SWOT strategy formulation for sorghum development in Wonogiri Central Java, 2022.

Factor Internals / Factor External	S Agro-Climate Supports	W Unstable Prices
O Demand for sorghum processed products and products is high	**S-O** Increasing productivity in accordance with regional agro-climatic conditions to meet the high demand for sorghum-processed products and products	**W-O** Collaboration with off-takers related to guaranteeing reasonable prices to increase production to meet the high demand for sorghum-processed products and products
T Pest attacks	**S-T** Optimizing cultivation techniques with innovative technology according to regional agro-climatic conditions to overcome pest attacks	**W-T** Collaboration with off-takers regarding guaranteed reasonable prices to increase income so that farmers have the financial ability to deal with pest attacks

Table 8. SWOT strategy formulation for sorghum development in Gunungkidul Yogyakarta, 2022.

Factor Internals / Factor External	S Land potential in the Third Growing Season and Unused Land	W Cultivation Is Not Yet Intensive/Traditional
O Market demand is high, and prices are starting to improve	**S-O** Take advantage of the land's potential with technology in increasing productivity and product quality to meet high market demand and prices that are starting to improve	**W-O** Improving more intensive cultivation of sorghum to meet market demands and improve prices
T Competitive land use	**S-T** Optimizing land in the third growing season and other fields to reduce competition in land use for other food crops	**W-T** Improving sorghum cultivation to reduce land use competition

To operationalize the strategy that has been formulated through the formulation of the SWOT strategy, each strategy is further translated into action plans that need to be implemented. The activity plan implemented in Central Java is different from that in Yogyakarta according to each operational policy strategy that is formulated. This operational policy strategy serves as a reference for policymakers in preparing sorghum development programs broadly in their respective regions. However, the results of this study have not shown the efficiency of sorghum production and sorghum development business institutions, so a more comprehensive study is needed on sorghum production efficiency by implementing sorghum cultivation standard operational procedures (SOPs) and a number of dimensions based on proper governance to establish sorghum development business institutions. The operational policy strategy for developing sorghum in Central Java and Yogyakarta is presented in Tables 9 and 10.

Table 9. Operational policy strategy for developing sorghum in Wonogiri Regency, Central Java.

Operational Policy Strategy	Activity
S-O Increasing productivity in accordance with regional agro-climatic conditions to meet the high demand for sorghum-processed products and products	(1) Make site-specific SOP for sorghum cultivation (2) Socialization and request for SOP implementation of site-specific sorghum cultivation to accelerate adoption (3) Preparation of maps of actual and potential land availability for large-scale development (4) Formulation of an action plan for potential land improvement for land improvement and optimization (5) Wide-scale development in accordance with land availability and suitability (6) Introduction of sorghum processing technology
S-T Optimizing cultivation techniques with innovative technology according to regional agro-climatic conditions to overcome pest attacks	(1) Application of site-specific SOP for sorghum cultivation (2) Integrated pest control technical guidance (3) Assistance and escort by field extension officers
W-O Collaboration with off-takers related to guaranteeing reasonable prices to increase production to meet the high demand for sorghum-processed products and products	(1) Making an MoU with the off-taker regarding occupation and a reasonable price (2) Introduction of primary and secondary processing of sorghum mechanization (3) Technology introduction and training on sorghum processing to increase added value (4) Improvement of sorghum business institutional governance involving the government, private sector, and farmers (5) Market expansion
W-T Collaboration with off-takers regarding guaranteed reasonable prices to increase income so that farmers have the financial ability to deal with pest attacks	(1) Making an MoU with the off-taker regarding occupation and a reasonable price

Noted: Source = Primary Data Analysis, 2022.

Table 10. Operational policy strategy for developing sorghum in Gunungkidul Regency, Yogyakarta.

Operational Policy Strategy	Activity
S-O Take advantage of the land's potential with technology in increasing productivity and product quality to meet high market demand and prices that are starting to improve	(1) Mapping actual and potential land suitability (2) Applying upstream cultivation technology by using high-yielding varieties and improving the cropping pattern (3) Application of processing technology for sorghum products according to SOP (4) Business meetings with partners and consumers (5) Doing MOU between farmer producers and off-takers (6) Application of an intercropping system with other plants (7) Selection of appropriate food or horticultural crops and having high economic value
S-T Optimizing land in the third growing season and other fields to reduce competition in land use for other food crops	(1) Application of an intercropping system with other plants (2) Selection of appropriate food or horticultural crops and having high economic value
W-O Improving more intensive cultivation of sorghum to meet market demands and improve prices	(1) Technical guidance on sorghum cultivation (2) Technical guidance on processing sorghum products and their derivatives
W-T Improving sorghum cultivation to reduce land use competition	(1) Application of intercropping and rotational intercropping technology (2) Use of early maturing varieties for the production of sorghum for food and sugarcane for livestock

Noted: Source = Primary Data Analysis, 2022.

5. Conclusions

Sorghum farming is feasible to be developed in Wonogiri Regency, Central Java, and Gunungkidul Regency, Yogyakarta because it provides a profit value greater than production costs with a BCR value of >1. The perception of farmers in Central Java regarding the development of sorghum is included in the very good category with an average value of 3.31, and the perception of farmers in Yogyakarta is included in the good category with an average value of 2.55. The priority strategy for developing sorghum in Wonogiri Central Java and Gunungkidul Yogyakarta is the expansion strategy (S-O). The operational policy strategy for developing sorghum in Wonogiri Central Java is: (1) Increasing productivity in accordance with regional agroclimatic conditions to meet the demand for high yields and processed sorghum products (S-O); (2) Optimizing cultivation techniques with innovative technologies according to regional agro-climatic conditions to overcome pest attacks (S-T); (3) Collaboration with off-takers related to guaranteeing reasonable prices to increase production in order to meet the high demand for sorghum processed products and products (W-O); and (4) Collaboration with off-takers related to reasonable price guarantees to increase income, so that farmers have the financial ability to deal with pest attacks (W-T). The operational policy strategy for developing sorghum in Gunungkidul Yogyakarta is: (1) Utilizing the potential of land with technology in increasing productivity and product quality and establishing partners (S-O); (2) Optimizing land in the third planting season and other land to reduce competition in land use for other food crops (S-T); (3) Improving more intensive sorghum cultivation techniques to meet market demand and improve prices (W-O); and (4) Improving sorghum cultivation technology to reduce land use competition (W-T).

Author Contributions: Conceptualization, S.W. (Sugeng Widodo), J.T., D.S., A.B.P., K., H.P., F.D.A., S., S.W. (Setyorini Widyayanti) and R.H.P.; methodology, S.W. (Sugeng Widodo), J.T., D.S., A.B.P., K., H.P., F.D.A., R.H.P., A.S.R., S., S.W. (Setyorini Widyayanti), A.Y.F. and M.; software, J.T., D.S., R.H.P. and A.S.R.; validation, S.W. (Sugeng Widodo), J.T., D.S., A.B.P., K., H.P., F.D.A., R.H.P., A.S.R., S., S.W. (Setyorini Widyayanti), A.Y.F. and M.; formal analysis, J.T., D.S., R.H.P. and A.S.R.; investigation, S.W. (Sugeng Widodo), J.T., D.S., A.B.P., K., H.P., F.D.A., R.H.P., A.S.R., S., S.W. (Setyorini Widyayanti), A.Y.F. and M.; resources, S.W., J.T., D.S., A.B.P., K., H.P., F.D.A., R.H.P., A.S.R., S., S.W. (Setyorini Widyayanti), A.Y.F. and M.; data curation, J.T., D.S., A.B.P., K., H.P., F.D.A., R.H.P., A.S.R., S., S.W. (Setyorini Widyayanti), A.Y.F. and M.; writing—original draft preparation, S.W., J.T., D.S., A.B.P., K., H.P., R.H.P., S., S.W. (Setyorini Widyayanti), A.S.R., A.Y.F. and M.; writing—review and editing, S.W., J.T., D.S., A.B.P., K., H.P., F.D.A., R.H.P., S., S.W. (Setyorini Widyayanti), A.S.R., A.Y.F. and M.; visualization, S.W. (Sugeng Widodo), J.T., D.S., R.H.P. and A.S.R.; supervision, A.Y.F. and M.; project administration, A.B.P., F.D.A., S.W. (Setyorini Widyayanti) and A.S.R.; funding ac-quisition, S.W. (Sugeng Widodo). All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Research and Innovation Agency of Indonesia through Research Organization for Governance, Economy, and Community Welfare through a research project entitled Prospects and Potential for Sorghum Development to Support Self-Reliance in Food, Animal Feed and Energy in the Central Area of Yogyakarta and Central Java. Grant number B-1832/III.12/PR.03.08/9/2022.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author. The data are not publicly available yet but will be in due course.

Acknowledgments: The authors express their gratitude to the National Research and Innovation Agency of Indonesia and thanks to Sugeng Hariyadi and Rismiyadi who have helped in collecting data in the field.

Conflicts of Interest: The authors declare no conflict of interest.

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Agricultural Transformation in the Rural Farmer Communities of Stung Chrey Bak, Kampong Chhnang Province, Cambodia

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Abstract: This paper examines the processes of agricultural transformation and their impacts within six rice farming communities in Cambodia. For this, we explored four drivers of agricultural transformation: (1) market integration, (2) modern technologies, (3) household assets, and (4) institutional-policy processes. The paper employs qualitative methods, using document analysis on the policy literature and datasets, field observations, focus groups, and key informant interviews in six rice farming communities in the Stung Chrey Bak Commune, Kampong Chhnang Province. Herein, we analyze the processes of agricultural transformation that shape farmer livelihoods and contribute to the literature regarding the dynamic and uneven politics of implementing the green revolution. Our findings show that agricultural transformation in the six rice farming communities has had mixed results. While the transitions have improved household income, they have also led to insecurity, with potential impacts on the long-term sustainability of the rice-production sector. These include higher input costs, fluctuating rice revenues, and environmental impacts from increased chemical use. We show that greater support is needed in these farming communities in order to achieve sustainable rice production going forward, particularly in light of climate change, indebtedness, and the migration of young labor to off-farm employment, leading to aging farmer populations.

Keywords: agrarian transformation; agricultural intensification; institutional-policy process; market integration; modern technologies

Citation: Kimkong, H.; Promphakping, B.; Hudson, H.; Day, S.C.J. Agricultural Transformation in the Rural Farmer Communities of Stung Chrey Bak, Kampong Chhnang Province, Cambodia. *Agriculture* **2023**, *13*, 308. https://doi.org/10.3390/agriculture13020308

Academic Editors: Hung-Hao Chang, Pei-An Liao and Jiun-Hao Wang

Received: 27 December 2022
Revised: 20 January 2023
Accepted: 24 January 2023
Published: 28 January 2023

1. Introduction

The world's agriculture has been shaped by neoliberalism over the last few decades. The agrarian transformation that is taking place in the developing world is predominantly shifting from traditional agriculture to integrations with urbanization, industrialization, and market-based production (Ravazi 2003 [1]). According to Vos (2018) [2], most Asian countries have undergone relatively rapid agricultural transformations over the past 50 years, which helped to rapidly grow their economic development. However, the agricultural transformations have differed markedly in their nature and speed across those countries of the region.

Cambodia's agricultural transformation was set back by the Khmer Rouge regime and the subsequent civil war. For Cambodia, integration into the international markets began in the 1990s following the transition towards democracy under the general election of 1990, wherein rice production has become an important agenda for the country's development (Razavi 2003 [1]). As a result, the land markets and speculation have brought in many companies, land investors, middle-men, and cash crop planters, along with migrants to the new frontiers of agricultural production that have reshaped indigenous communities, social and gendered relations, and the movements of capital (Park and Maffii, 2017 [3]).

With the recognition of market forces, the government of Cambodia passed the Subdecree on contract farming in 2011 with the aim of improving market access and productivity (Sreymo, & Pirom, 2015 [4]).

While the country has experienced growth in the agricultural sector which has contributed to the GDP, in 2017, the agricultural share of GDP was around 19.1%, the share of agriculture is (similarly to the transitioning economy) in a declining trend, but growth within the agricultural sectors continues. The share of GDP growth from the agricultural sector has declined since the early 1990s, with tourism, garment manufacturing, and construction dominating the nonagricultural economy (Hill and Menon, 2014 [5]). According to FAO data (2022) [6], the share of agriculture, forestry, and fisheries as a total of GDP fell from 45% in 2000 to 21.7% in 2020. (For comparison, in neighboring Thailand, it dropped from 12.7 to 8.7, and in Vietnam, from 26.8% to 14.4%).

The role of agricultural growth in development has been subject to much debate as to whether the aims of growth in GDP and poverty alleviation are met simultaneously (Christiaensen, Demery, and Kuhl, 2010 [7]). In 2015, over 56% of the working-age population of the country was employed in the agriculture sector (ODC 2020 [8]). The World Bank reported that over 60% of poverty reduction in Cambodia during the end of the 2000s and early 2010s was attributed to agricultural growth (World Bank, 2015 [9]). Cambodia's agricultural growth rate in the 2000s was the highest in the world (5.3%), with rice production predominantly contributing toward this.

However, the growth experienced after the 2000s was achieved through agricultural intensification and has relied on the reliance on costly inputs, such as agriculture mechanization, pesticides, new crop varieties, and chemical fertilizer (MAFF, 2018 [10]). This realm of transformation reflects the green revolution that was generated during the 1970s and was widespread in the Global South (Castella, 2012 [11]). Furthermore, growth has involved access to local and global markets.

The agricultural transformation in Cambodia has not taken place without its problems for rice-growing communities. For example World Bank (2015) [9] looked at farm incomes from rice compared with different crops and found that, in Cambodia, income per hectare was higher for vegetables (USD 2843/ha) and cassava (USD 1297/ha) with dry season rice in the middle (USD 992/ha) and wet season rice (USD 756/ha) and maize (USD 744/ha) at the bottom, which reveals the market factors in the regional trends for rice farmers to move to more profitable crops. Changes in export partners have also impacted rice farming incomes. While China has become a new market for rice export, the revenue is lower than that which was formally obtained from the EU, with farmers being the most affected, as middle men adjust buying prices to avoid losses (Hutt, 2020 [12]). Cambodia also faces future uncertainty in microfinance indebtedness, which reached USUSD 4213 per capita in 2021, and is more than double the GDP per capita (Guermond et al. 2022 [13]), to which smallholder farmers are increasingly contributing to (Green 2022 [14]). Furthermore, some reports point to the negative impacts of modern agricultural inputs, especially chemical use in agriculture. For instance, Silva, Johnston, and Try (2013) [15] found that the chemical used in rice growing poisons fish in the rice field, therefore reducing traditional fishing products. The loss of income from fishing has led to some fishing households diversifying into rice farming, often encroaching on forest lands. This presents a feedback loop in environmental and climate change vulnerability for rice farming, with the sector being the main water user in Cambodia (Wokker et al. 2011 [16]). In recent years, increasingly irregular rainfall, generally associated with climate change, has adversely affected crop production and led to water conflicts among farmers (Nang et al. 2011: 37–39 [17]). Purvis et al. (2019) [18] argue that the concept of sustainable agricultural intensification requires careful consideration of the potential trade-offs between the social/human, environmental, and production/economic outcomes. The complexities in the rapid transformation of agriculture in Cambodia, thus, require further exploration into the consequences on the livelihoods of local people and the broader development outcomes in order to achieve sustainable outcomes.

This paper highlights the need for a view beyond the one-size-fits-all view within the green revolution, highlighting the need for context for the village- and household-specific nonlinear adoption of green revolution farming practice. This paper examines the processes of agricultural transformation and their impacts on livelihoods using a case study approach, looking at six farming communities within the Stung Chrey Bak catchment. The first section of this paper presents a review of the literature, analyzing debates on the nature of transformations and their impacts. Following that, the methodology is presented, in which the analytical approach and data collection methods are explained, followed by the results from our qualitative data in four areas of transformation: agricultural technologies, market integration, household capital assets, and institutional and policy processes. Finally, the discussion and conclusion section outlines the complex and uneven outcomes of agricultural transformation that create differentiated opportunities for different scales of farming. We explore how small-scale farmers are disadvantaged, the reshaping of the social and economic capitals of agricultural households, and the varied outcomes of adopting 'modern' agricultural inputs and machinery, including recommendations for policy makers. We anticipate that this study offers a valuable contribution to the literature on the nature of the uneven politics of agricultural transformations, with a particular focus on sustainable rural livelihoods, by presenting the effects of national policy and global markets at the local scale.

2. Materials and Methods

2.1. Literature Review

Under globalized neoliberalism, state roles in agriculture, such as price stabilizations and different forms of subsidies, are limited. Agrarian production relations, thus, have transformed into market relations at a global scale—global capitals come into play in shifting the surplus production as a means of funding a modernized economy (Hart et al. 1989 [19]). Meanwhile, agricultural 'modernization' processes have taken place, characterized by the unequal implementation of the 'green revolution'. Within this, agricultural transformation is centered around processes of productivity improvement (Pingali 2023 [20]) and the use of modern agricultural inputs to obtain more outputs on the same size of land. There is a growing concern over the various trade-offs of rapid transformation and marketization, particularly the negative impacts on local livelihoods. Agricultural innovations have been touted to be essential to the development of sustainable rural livelihoods rooted in the perceived successes of the green revolution that had lifted millions towards food security (Mutsvangwa-Sammie and Manzungu 2021 [21]). The same study argues, however, that the positivist narrative surrounding these innovations overlooks the nuances of the biophysical, socioeconomic, and cultural aspects, alongside the political economies of scale of agricultural production, and the fact that rural livelihoods cannot be so simply defined as they become increasingly diversified. The agricultural revolution has composited other issues with implications for smallholder farmers; for example, Anti (2021) [22] argues that large-scale land acquisitions (LSLAs) cause a shift away from independent agricultural production towards employment in agricultural labor in adjacent regions.

A number of studies show that the processes of agricultural transformation are not universal but are context-specific. For example, regional studies show that transition processes are not uniform across Asia (Viswanathan et al. 2012 [23]) and provide perplexing, contradictory, and paradoxical effects, which can at once empower and dispossess (Choenkwan and Fisher 2018 [24]).

Viswanathan et al. (2012) [23] argue that, rather than understanding microenvironments, planning takes place at the macro level. The green revolution has been promoted as a universalistic paradigm, with templates used in places that have vastly different contexts (Graham and Pino 2012 [25]). Transformation is shaped by specific historical paths, politics, and socioeconomics at the national and subnational scale; for example: average land sizes (Viswanathan 2012 [23]); extent of land grabbing (Schoenberger, Hall, and Vandergeest 2017 [26]); investment in research and technology transfer (Pray and Fuglie 2001 [27]), and

microfinance over-indebtedness (Green 2022 [14]). Impacts also vary by place and can be paradoxical; Das (2002) [28] argues there have been no statistical relationships to poverty reduction, particularly where persistent poverty can be characterized by both technological advancement and the lack of it (Das, 2002 [28]); Gill & Singh (2006) [29] report on farmer suicides in India due to debt-related stress occurring two decades after the green revolution. Increased agricultural production is achieved partly through market integration, which is achieved through the conducive policy environments for the private sector or 'markets' to operate (World Bank, 2015 [9]). Some research has indicated that compliance with the liberalization of agricultural policy is necessary to improve and promote the quality of life among rural farmers, with improved agricultural productivity claimed as being critical to the growth of income and well-being for household farmers (Brown and Haddad 1994 [30], Iheke and Arikaibe 2012 [31], Bhandari, 2017 [32]). Contract farming is generally seen as a means to deal with both the problem of access to agricultural inputs and marketing (Reardon et al., 2019 [33]); however, the negative impacts of contract farming are differentiated; for example, Olounlade et al. 2020 [34] found an unevenness of economic distribution between smallholders and large agribusiness, as well as negative impacts on health and the environment, with the lowering of incomes affecting some but not all farmers (Olounlade, et al. 2020 [34]). There is an uneven ability among farmers to adopt modern agricultural inputs due to their limited access to land, financial capital, and labor, and some have found interventions being subject to elite capture (Mdee et al. 2021 [35]). A number of rice farmers have chosen to invest their labor into more attractive off-farm employment (Tomich et al. 1995 [36]).

Agricultural transformation is said to inhibit the rural-to-urban migration of people. However, the interpretation of migration remains divided. Modernization theory sees migration as being pushed by rural poverty or pulled by the higher wages of urban industries (Lee, 1966 [37]). However, the sustainable livelihood framework sees migration as part of the household strategies for achieving and maintaining a desirable level of quality of life or well-being, which is one of a portfolio of 'capital assets' that, together with the labor force, are utilized to achieve the best possible outcomes (Chambers and Conway 1992 [38]). Labor migration and aging rural populations have long been a concern for policymakers. In low- and middle-income countries, aging farmer demographics in low- and middle-income countries is said to pose potentially negative implications for agricultural production and food security, while others point to insufficient evidence to draw such conclusions (Heide-Ottosen 2014 [39]).

2.2. Methodologies

2.2.1. Analytical Framework

From the literature review above, we draw a framework that demonstrates a causal structure of factors driving agricultural transformation, which is presented in Figure 1. The diagram identifies the four components of agricultural transformation, including agricultural technologies, market integration, household capital assets, and institutional and policy processes. From these, we investigate the drivers and processes that shape transformation in rice production at the local level. Our analytical approach looks at how these processes reveal economic challenges and livelihood risks and benefits at the household level, including access to technologies, the market, and labor, as well as changes in income and support from policy and institutions aimed at farmers. We investigate how these reflect on the uneven politics of the green revolution and speculate what these might mean for sustainable livelihoods and rice production among Stueng Chrey Bak farmers in the future.

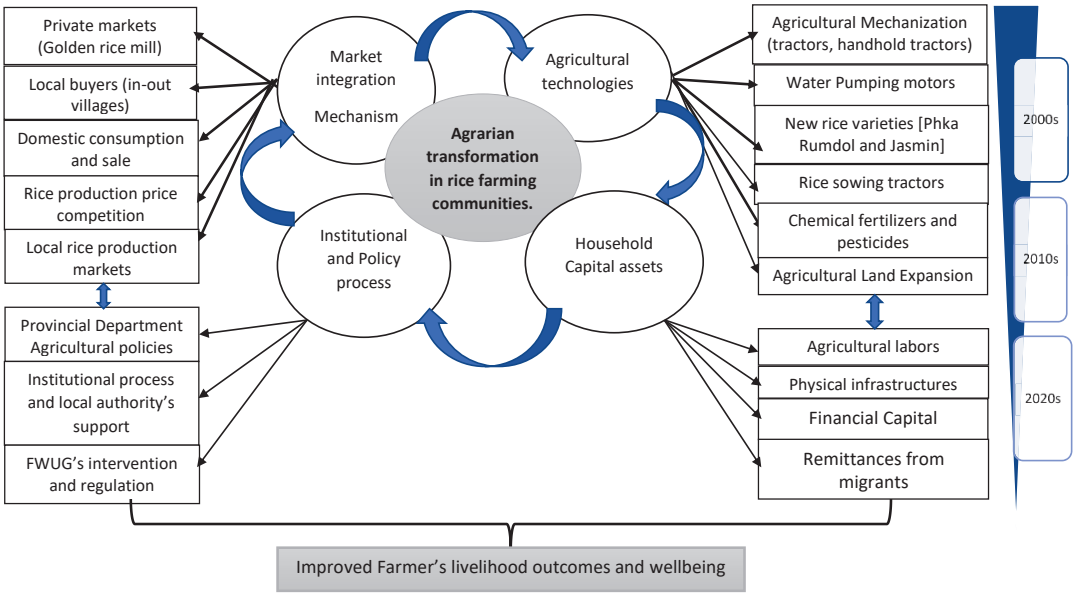

Figure 1. Analytical, conceptual framework on the agrarian transformation of Tang Krasang and Trapang Trabek rice farming communities. Source: Author, 12 June 2022.

Figure 1 shows how the components of agricultural transformation used in the conceptual framework in the themes of agricultural technologies, the integration of market integration, household capital assets, and institutional and policy processes components have nonlinear relationships.

2.2.2. Site Selection

The Stung Chrey Bak is situated in the Southwest of Kampong Chhnang Province. The Stung Chrey Bak covers an 80 km stream, a medium-size tributary, originating from the Cardamom Mountains, and drains water from a total catchment area of 663 km^2 into the Tonle Sap river. It shares a border with the Teuk Pos and Rolea Bier districts. Stung Chrey Bak is remote and sparsely populated, with a distance of close to 90 km from the nation's capital, Phnom Penh (Sam and Pech 2015 [40]).

Stung Chrey Bak was selected as a study site because of its relatively high incidence of poverty and high dependency on natural resources. Stung Chrey Bak has multiple functions for providing rain for rice production and is rich in natural resources ((Sam and Pech 2015 [40]).

However, studies have shown that the communities face increasing vulnerability due to their strong dependence on water, land, and forest resources and projected increases in climate change-related impacts, relatively poor water governance, and limited resilience strategies (Sam and Pech 2015 [40]).

Two rice farming communities within the Stung Chrey Bak (see Figure 2) were chosen: the Tang Krasang and Trapang Trabek communities. Tang Krasang's community is situated upstream, in the middle part of the catchment. Three villages, named Tamom, Tang Krasang, and Chas, were selected randomly among the total of five villages in the Tang Krasang commune, Teok Pos district.

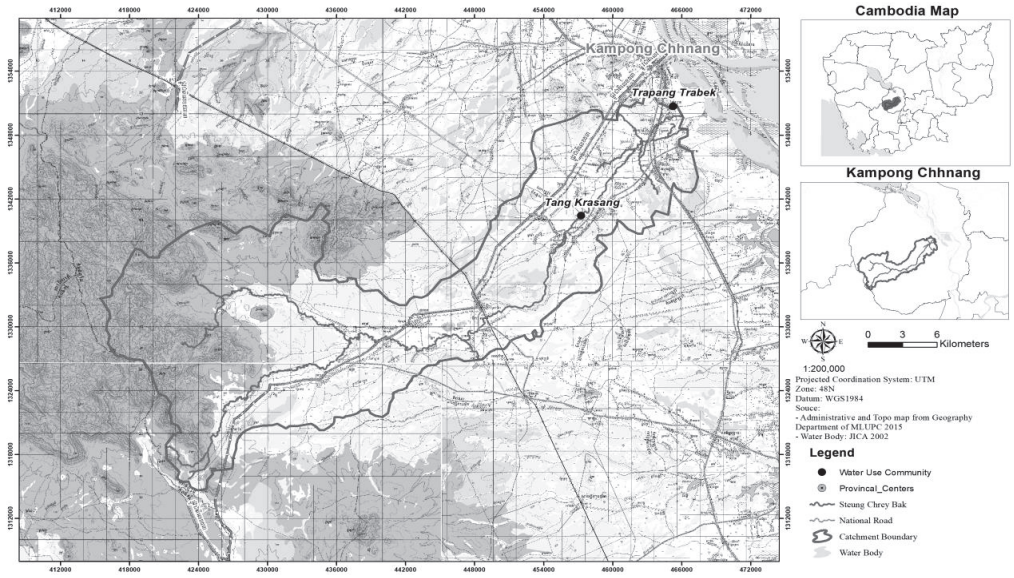

Figure 2. Map of the locations of the farming communities in the Stung Chrey Bak catchment. Source: Author, 12 June 2022.

The Trapang Trabek community is located downstream of Stung Chrey Bak, joining the Tonle Sap Lake. Three villages: Kouk Beanteay, Popeal Pork, and Proneam Pich were selected randomly among the total of four villages in the Kouk Beanteay commune.

2.2.3. Research Method

The qualitative methods that were used for data collection included document analysis, field observation, focus groups, and key informant interviews. Document analysis used datasets acquired from relevant ministries, including the Ministry of Water Resource and Meteorology, The Ministry of Agriculture, Forestry and Fisheries, The Ministry of Environment, and The Ministry of Rural Development, and annual reports were taken from provincial department lines. By using qualitative methods, we were able to understand the how and why of the processes and relationships of transformation from the perspectives of the community. We began with field observations aimed at identifying key provincial and local people who facilitated access to the participants from their networks. From this, two representatives from each of the farming communities of Tang Krasang and Trapang Trabek were selected to contact individuals for focus group discussions. The two focus group discussions (FCDs) concentrated on village history, livelihood diversification, rice production marketing, water-use problems, and household capital assets, such as labor division.

Rice farming systems were discussed with the help of a resource-mapping activity. Key informant interviews (KIIs) were conducted with 25 participants who were selected from the four different governance scales, including village, commune, district, and province levels. These were chosen due to their in-depth knowledge of the changing situation of rice farming and how they cope with the changes. They included four representatives from the provincial departments, two representatives from the district's governors, four representatives from the commune heads, six people from the village heads, four representatives from FWUCs, one high school teacher, two people who were local rice-buyers, and two representatives from the private rice companies.

3. Results and Discussion

3.1. Results

From our interviews, we found that the population in the three study villages in the Tang Krasang commune were predominantly farmers growing wet-season rice, and some farmers have increased their land size for growing dry-season rice. In the three study villages in the Trapang Trabek commune, the farmers are growing dry-season rice. These six selected villages share a river for rice growing during both the wet and dry rice seasons and have access to natural resources, such as fishing and the collection of nontimber forest products, and share a similarity of sociocultural values and agricultural markets.

3.1.1. Farm Mechanization

The interviews and focus group discussions revealed that, from 2010, changes in agricultural practices were evident in all six villages. The farmers indicated that, in the 1980s, a large population of farmers in Tang Krasang and Trapang Trabek relied on animal labor (buffalo) for plowing, transplanting, and transporting and human labor (family members) for rice growing, including land preparation, transplanting, and harvesting. Rice farmers increasingly turned to the use of machinery, such as modern tractors and water-pump machines. The replacement of buffaloes with machines has been evident since 2010. Initially, two-wheel tractors (2W) were introduced and quickly became widespread; later, four-wheel tractors (4W) grew common. Our interviews and focus group discussion counted that 161 farmers used 2W tractors in the six villages. In total, 97.2% of farmers used tractors, and 2.8% used animal and human labor forces. From 2018 onwards, there was a change from 2W tractors to 4W tractors. Most farmers in both communities reported that, in 2018, eight farmers owned 4W tractors. In 2020, the number of 4W tractors increased to 11, as the farmers in the Trapang Trabek community owned seven 4W tractors. At the time of the study in 2021, we found that there were 17 4W tractors owned by farmers. The focus group discussions in the Chas and Tang Krasang villages indicated that about 82% used 4W tractors (hired), while only 18% used 2W tractors. The changing mechanization of rice growing over the period between 2010 to 2021 is shown in Figure 3.

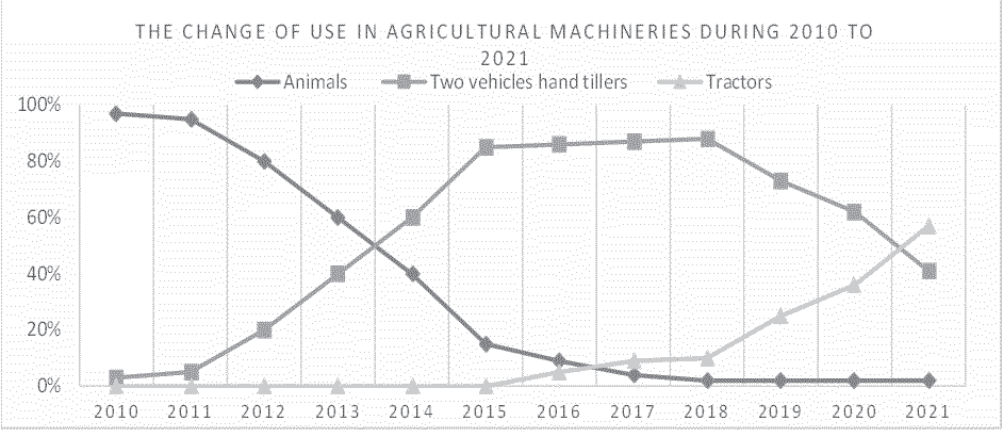

Figure 3. Agricultural machineries in communities from 2010 to 2021. Source: fieldwork, 2021.

Our results show that, in comparison to the figures for Thailand (100%) and Vietnam (80%) (Hossen 2020 [41]), our study site falls in the middle (97.2%) for the extent of adoption of machinery.

As most farmers do not own tractors, they hire machines to prepare the land. Hiring a 2W tractor costs KHR 200,000 riels (USD 50) to prepare one hectare of paddy. The difference in costs for hiring is evident. A 4W tractor costs KHR 800,000 (USD 200), and manual labor

costs KHR 350,000 (USD 87.5). The physical geography of the paddy fields also influences farmers' choice of tractors. For instance, Trapang Trabek, as a part of Tonle Sap Lake, has a hard clay soil type and is muddy, which is suited to the 4W tractor. Farmers in Trapang Trabek told us that while a 4W tractor takes one hour per hectare to cultivate paddy land, 2W tractors take 2–3 h per hectare. On the other hand, the farmers in Tang Krasang, which is in the middle part of the catchment, and has a hard-dry-sandy soil type resulting from soil erosion from a mountainous area, are better suited to a 2W tractor for their paddy field preparation. Tractor owners providing land-preparing services have increased over time, and some also extend their business to cover other types of agricultural inputs.

3.1.2. New Rice Seed Varieties

From the 1980s to 2000s, farmers cultivated rice varieties known as IR36, Neang Kok, and Sen Pidor; however, our interviews with the community leaders revealed that over 80% of the farmers in both communities now use a hybrid rice variety known "Phka Krovan". This rice variety was widely introduced to farmers in early 2015 by Kampong Chhnang's provincial department of agriculture, forestry, and fisheries and local authorities. It has been widely adopted for having a shorter crop growing period, greater yield, and is better adapted to limited rainfall than existing varieties. Farmers also view Phka Krovan as effective in attracting good prices in the markets. The Phka Krovan rice has a growth period of medium duration and is a photoperiod-sensitive variety. However, the use of the new rice variety requires the adoption of modern agricultural inputs, such as fertilizers, pesticides, and diesel engine water pumps. Figure 4 shows that the greater yields from the adoption of Phka Krovan are linked to the increased use of machinery, chemical fertilizers, pesticides, and the adoption of diesel water pumps.

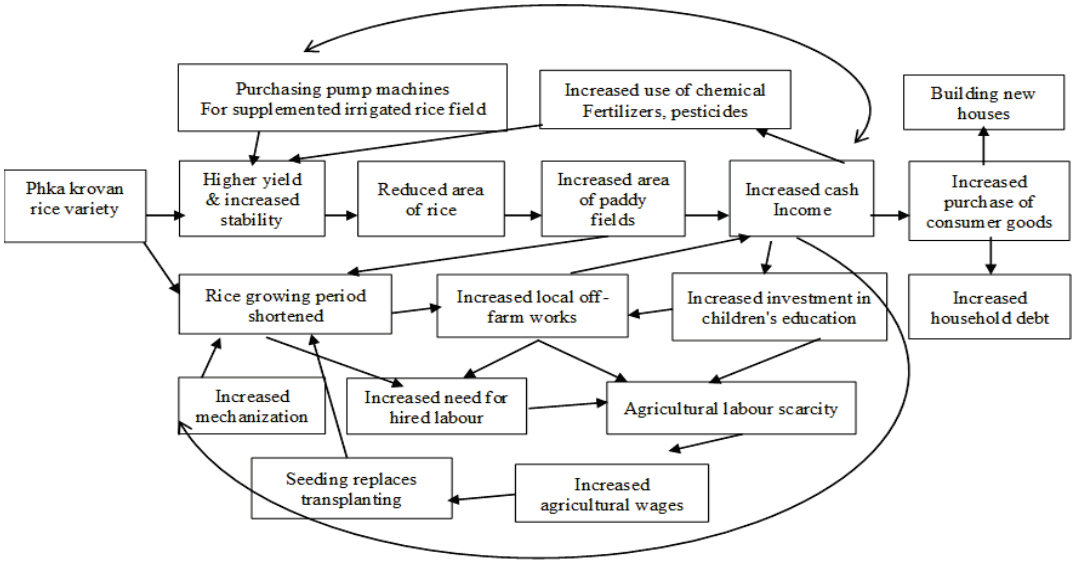

Figure 4. Household rice production in the communities. Source: author, 2021.

The shorter period of time of rice growing, together with the use of machines, permits some laborers to engage in off-farm employment. Other interviews reveal an evident increase in rice yield and, therefore, a higher income from rice growing. However, most of the income is spent on agricultural inputs, as shown above in tractor hire. Furthermore, access to modern agricultural inputs is uneven, with the results showing that middle- and large-scale farmers are more likely to adopt modern agricultural inputs than small-scale farmers with less than one hectare of paddy field.

3.1.3. Chemical Fertilizers and Pesticides

From the early 2010s, farmers turned to the heavy use of chemical fertilizers, which enables plant nutrients and good yields in adverse weather conditions when rice requires additional nutrients. The intensification of chemical fertilizers increases the yield of rice crops but raises a number of questions regarding productivity and sustainability. Farmers reported that the chemical fertilizer used amounted to half a bag (25 kg) per hectare of rice fields in the 1980s. This increased to two bags in the 1990s and further increased to six bags per hectare in 2019. In the interviews, the farmers revealed that their yield per hectare increased from four to six tons. The increase in paddy yield, following the increase in chemical fertilizer used, reached 6 tons per hectare during 2020 and 2021.

Three different types of chemical fertilizers were found in the studied villages; Urea (46-0-0) Black buffalo Head made in Vietnam, White-Urea (49-0-0) made in Thailand, and Sunrise made in Japan. All of these are imports, with their prices tied to international exchange rates, with a trend of increasing prices. In 2010, the price of one bag of chemical fertilizer (50 kg) was KHZ 80,000 (USD 20). The price rose to KHZ 120,000 (USD 30) per bag between 2017 and the time of data collection. Even with the price of chemical fertilizers continuing to soar, farmers are required to purchase them, as, without them, the yield will be insufficient to meet demand. A few of the farmers we interviewed pointed to the overuse of chemical fertilizers causing negative impacts, damaging rice paddies, with the soil composition becoming harder and infertile. In the Chas, Tamom, and Preah Neampich villages, the farmers reported concerns about water pollution, chemical burning of crops, the acidification of the soil, and mineral depletion in the soil. However, a number of villagers showed a reluctance to use organic fertilizers, even though they were cheaper, due to them producing lower rice yields.

According to the Word Bank (2015) [9], the adoption of fertilizers by farmers in Cambodia might have been previously low due to the high risk of obtaining tainted, low-quality fertilizers in the marketplace. However, they found that the availability of low-quality and sometimes fake fertilizers sold in Cambodia does not appear to be a major issue (WB, 2015 [9]).

3.1.4. Market Integration

A key component of the agrarian transformation is market integration; during the Khmer Rouge, the market was nonexistent. Shifting market integrations consisted of the following types of markets; exchange, wax-markets, community markets, and regional markets. The markets have grown from interhousehold exchanges of produce to regional markets selling imported goods (Figure 5). From the 1980s to the early 1990s, farmers produced rice for their own consumption or exchanged their produce with other households. From the 1990s, farmers traded products in 'wax markets', deriving their name from the melting of beeswax by heat, which functioned in the morning until after sunset. These markets sold agricultural commodities, such as rice, fish (caught from the paddy fields, canals, and reservoirs), home-grown vegetables, meats, groceries, and nontimber forest products (NTFPs). Wax markets then expanded to supply more products in community markets, particularly rice. Home-scale markets received limited imported products and services. From the 2000s, markets grew to the domestic scale and then the middle scale, with an increasing diversity of products, services, and buyers from outside the communities. This was enabled due to the construction of a concrete road in 2015, which helped farmers in Tang Krasang access the Prey Khmer market. In the 2020s, markets have grown to a regional scale. Market growth has coincided with increased farmer household wealth, creating greater demand for imported goods and services, including agricultural inputs and machinery. Rice production has grown with rapidly increasing rice yields for the regional market, resulting from the intensification of rice production from the farms, growing to a middle-scale level, which has attracted more buyers and companies. This has been accomplished with the expansion of the paddy fields and the use of modern agricultural inputs, such as new rice varieties, fertilizers, pesticides, and machinery.

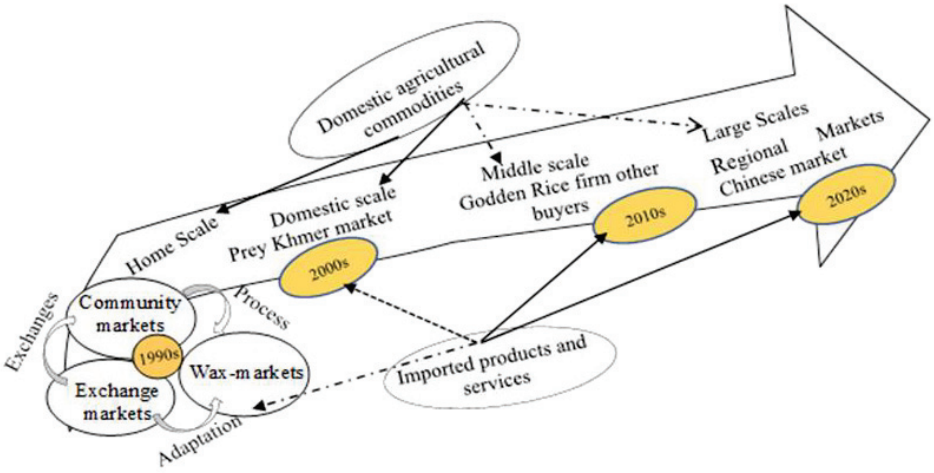

Figure 5. Market Integration in the Tang Krasang and Trapang Trabek rice farming communities. Source: author, 2021.

The market integration of paddy production into our studied sites has meant that local family farms are now drawn into market mechanisms. This integration has resulted in improved productivity, but the increase in yields is accompanied by increases in expenses, and in order to maintain favorable profits, farmers must maintain or increase the scale of their production, particularly their land size. Our interviews revealed that those who are satisfied with the market prices are middle and larger farms, while smaller production scales (less than 1 ha) are disadvantaged. The market integration in this respect seems to pave the way for the larger scale of production, and this reflects the work of the 'economy of scale'.

3.1.5. Migration and Off-Farm Employment

One of the challenges that farmers frequently raised during the interviews was soaring labor costs for rice growing. Finding human labor for harvesting is difficult because young labor typically migrates out of the villages to seek higher-paid employment in other industries. As a result, migration to off-farm employment causes labor shortages and has driven wage increases in agriculture; the cost of labor for one ha paddy harvest has risen to KHR 450,000 (USD 110).

In Tang Krasang and Trapang Trabek, the farmers reported that over 60% of the active labor forces have migrated and/or are employed in off-farm jobs. Young females are dominantly working in the garment sectors, while males are working in the construction sector. The presence of local garment factories presents a good opportunity for young female employment. Around 35 garment factories were established in nearby village areas in 2010, and the number increased to 56 in 2019. Furthermore, localized employment also allows young labor forces to contribute to farming on weekends and holidays, which partially eases the labor shortages in the agricultural sector. The local livelihoods of the farmers are, thus, shaped by multiple socioeconomic conditions. On the one side, farmers are reliant on their land, while laborers who till the land are increasingly scarce, causing farmers to turn to mechanization to replace human labor. Despite this, agricultural outputs cannot satisfy capital needs, and therefore farmers seek off-farm employment. Those farmers choosing to remain in agriculture seem to be determined by the size of their land; if their land is smaller than 1 ha, there is a strong likelihood that they exit agriculture and rely entirely on off-farm employment.

The combination of nonfarm work (garment factories and construction) and agriculture seems to be the best plausible livelihood option for local people. However, this option

is dependent on the dynamic changes in both the agriculture and local industrial sectors. In this respect, the livelihoods of local farmers are unsettled. In the short term, people seem to be satisfied with the increase in income; however, modern agricultural inputs are increasing. Local people opt to smooth out their livelihood outcomes by diversifying the use of human capital assets. The desirable livelihood outcomes may alter following a change in both the agriculture and modern industrial sectors.

3.1.6. Impacts from Institutional Policy Processes on Agricultural Transformation at the Farming Community and Local Level

The creation of farmer water user committees (FWUCs) in each community was undertaken in the early 2000s and was initially supported by the Provincial Department of Water Resource and Meteorology (PDOWRAM) and the local authorities. Their aim is to address the increase in competition for water, which was sparked by the development of irrigation systems. FWUCs work closely with farmers, who are ultimately the irrigation beneficiaries. The role of FWUCs is to manage, regulate, and distribute water from the main canals to the rice fields, address flood and drought problems for farmers, mobilize water users to rehabilitate and repair the canals when needed, and negotiate with other communities to address upstream and downstream water conflicts.

Some of the operational challenges that FWUCs face were found in the study. The FWUCs have an insufficient budget to enable them to carry out the work. FWUC members work on a voluntary basis, usually for many years, and the absence of incentives limits their work and commitment. The management committee of an FWUC consists of a nominal five people per community, but only one person, as the head of an FWUC, actively works on issues. FWUC relies on the help of commune councilors in areas such as conflict resolution, which typically occurs during water shortages in the dry season. This is primarily due to the influence that commune chiefs have established in the community through their assistance in many interventions, such as providing microfinance loans and supporting other social activities. However, the intervention from the commune council has, to some degree, negatively impacted the functioning of FWUCs due to commune chiefs being local politicians affiliated with political parties. FWUCs, by law, are nominally required to be independent. Therefore, the involvement of the council has stripped the FWUCs of accreditation as a local independent entity (Chem, 2013 [42]). The constraints they face in their financial and technical capacity also leads to them depending upon outsiders, such as the provincial department of water resource and meteorology (PDOWRAM) and local authorities to support them.

3.2. Discussion

The agricultural transformation of the rice farming communities of Tang Krasang and Trapang Trabek has been shaped by an export market that is centered on policy and modern technologies, which includes the uptake of agricultural mechanization and the application of agricultural inputs, such as new seed varieties, chemical fertilizers, chemical insecticides, and pest controls.

The uptake of machinery among farmers has been high; however, the benefits are differentiated, with some farmers buying tractors for rental purposes, while others are burdened with the extra cost of machinery in comparison to human and animal labor. New rice varieties have also coincided with adopting 'modernized' approaches to agricultural inputs, particularly the variant of Phka Krovan, which is linked to increasing and intensified chemical fertilizer and pesticide usage. The heavier emphasis on chemical fertilizers and pesticides on paddy fields poses negative long-term impacts on the quality of paddy field soil, farmer health, and natural ecology. Agricultural transformation also results in the dependence of Cambodian agriculture on modern international agricultural input markets.

The intensification of the use of modern technologies happened alongside the market integration of agricultural households through the expansion of traditional 'wax markets', involving a shift in the rural economy of rice production (for household consumption)

toward market orientation. Integration into international markets increasingly demands mechanization and the improvement of yields at the farm level, putting greater pressure on requiring increasing agricultural inputs and an increased burden on loaning equipment and financial capital. Rice prices are now strongly linked to export competition and currency value. Price fluctuations mean that farmers, who are faced with low rice prices, see their farms becoming less attractive for laborers, and subsequently, many migrate to alternative off-farm employment. This coincides with rice farming households increasingly relying on incomes from off-farm sources to supplement this, agriculture declining in its importance for subsistence, and the increasing costs of modern inputs, as more young-generation laborers look to escape agriculture, ultimately resulting in agricultural labor shortages.

There has been much debate on the growth of circular migrant labor both to and from the agrarian regions of the global south in attempts to understand the relationships between the mobilities of labor and smallholder capital alongside large-scale land acquisitions and industrialized farming (Kelly et al. (2020) [43]). The agricultural transformation of farming communities in Stung Chrey Bak coincides with the migration of the young generation to work in urban industries in towns and cities throughout Cambodia. However, in this case, the garment industries had relocated to the local area, so a great number of young members of the local agricultural households were employed. This allows young labor forces to be involved in agricultural labor alongside employment in other off-farm industries during vacations or before/after working hours. In this way, the transformation process of local agriculture also reflects the reorganization of household assets, especially the diversification of investment of human capital.

The coexistence of agriculture and the garment industry in our case study contributes towards the continuity of agricultural households, but it is uncertain whether this is sustainable for the long term. Thus, understanding the dynamics of household capital assets plays a key role in understanding livelihood security. With limited capital assets, households may diversify the investments of their capital assets into both on-farm and off-farm activities. Recently, rice growing has become largely conducted by elder farmers, while the majority of young laborers are engaged in off-farm jobs. This type of investment, although allowing for the viability of a household in the short term, is challenging over the long term. These findings agree with the trends reported elsewhere, which concern the future of rural communities and food production in light of aging demographics (Heide-Ottosen 2014 [39]). Furthermore, this can be seen within the lens of increasing marketization, and land scarcity has reshaped gender roles and relations in other Cambodian provinces, where resource politics have alienated many prior landowners from their lands, with this hampering social reproduction (Park and Maffii 2017 [3]). Other scholars have realized a feminization of household agricultural roles in Nepal under the transition from an agrarian society, in which there is a shortage of male labor from outmigration (Pandit 2017 [44]). Meanwhile, these altering relations have marginalized many older generation farmers, particularly elder women based on emphasizing the value of financial capital, possession of goods, and concepts of modernity (Park and Maffii 2017 [3]).

The institutional-policy process plays a very important role in supporting farmers through farmer water user communities (FWUCs). The most effective level of influence vis-a-vis the daily operation of the FWUCs is at the commune level. Its role is to arrange the necessary public services and promote socioeconomic development and agricultural productivity. Despite this, the objectivity of the solutions can be called into question with commune chiefs' associations with political parties, and their efficiency can be hampered by operation on a voluntary basis.

4. Conclusions

In conclusion, agriculture has become more diverse, with the multifunctional rice farming communities of Tang Krasang and Trapang Trabek providing higher incomes as a part of livelihood improvement. Yet, while household income has improved among farming communities due to both increased yields and supplementary incomes from off-

farm employment, the increased costs of the inputs and lower rice prices have meant farmers are facing greater risks. As other studies show, Cambodia's widespread uptake of microfinance loans in response to rising input costs, which has already deepened the debt and financial shocks, including those with land held as collateral, has meant that farmers are at risk of losing their land and livelihoods, and this, in turn, contributes to out-migration and increasing debt burdens (Bylander 2013 [45], 2015 [46]).

We recommend policymakers look to supporting farming communities with improved water infrastructure, particularly for small-scale farmers where little provision currently exists. Market approaches that focus on export targets that lead to the intensification of rice production need to be decoupled from the low commodity pricing of rice to enable long-term sustainability in rice farming and rural livelihoods. This is important in light of Cambodia's competitive position in the regional rice market, wherein Cambodia is in competition with neighboring countries, some of which provide state subsidies, and have recently lost the advantage of having the EU as the primary export partner, being replaced by China who imports a greater quantity but at lower prices.

The time and funding limitations of this study meant that nonfarmers and those who had stopped farming for more than five years were not interviewed. Further research should look at other factors influencing the livelihoods of rice farming communities, such as indebtedness and land ownership. Furthermore, the long-term impacts related to soil and food quality from the intensive use of fertilizers and pesticides among farmers' plots warrant further research. Research on farmers' perceptions of well-being is forthcoming from the authors.

Author Contributions: Original Conceptualization B.P., H.K.; methodology, B.P., H.K., B.P., H.K.; H.H.; S.C.J.D., formal analysis, B.P., H.K.; H.H.; S.C.J.D.; investigation, B.P., H.K.; data curation, H.K.; writing—original draft preparation, B.P., H.K.; H.H.; S.C.J.D.; writing—review and editing, B.P., H.H.; S.C.J.D., visualization, H.K.; supervision, B.P.; project administration, B.P., H.K.; funding acquisition, H.K. All authors have read and agreed to the published version of the manuscript.

Funding: This paper was funded by a scholarship from the Faculty of Humanities and Social Sciences, Khon Kaen University, Thailand.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: It was obtained from all subjects involved in the study.

Data Availability Statement: We confirm. We do not have the research participants consent to make their data available for other projects.

Acknowledgments: The author would like to express gratitude to Buapun Promphakping, Khon Kaen University, for his valuable advice as my Ph.D. supervisor. The author also wishes to thank Thanapruge Chamaratana, the Faculty of Humanities and Social Science, Khon Kaen University. Isanka Gamage of TIIKM Publishing for a crucial editing of the first draft of this paper. The author wishes to thank the three anonymous reviewers for their valuable comments. We are also grateful for the support from Khon Kaen University and the critical and useful contribution of those who participated in our study in the Stung Chrey Bak community.

Conflicts of Interest: There are no conflict of interest in this paper.

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Does COVID-19 Affect Farmland Prices? How and Why?

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Abstract: COVID-19 has profoundly impacted the global economy, particularly the agricultural sector. However, relatively little attention has been paid to the relationship between COVID-19 and the farmland market. A few descriptive studies have speculated about the impact of COVID-19 on farmland prices but presented no quantitative evidence. This study provides quantitative evidence on the causal effect of COVID-19 on farmland prices using the difference-in-differences method with population-based data on farmland transactions in Taiwan. While prior descriptive studies argued that increased farmland prices associated with COVID-19 were largely driven by macroeconomic conditions, we found that the onset of COVID-19 increased farmland prices by 5.1%, even after controlling for macroeconomic conditions and parcel-level farmland characteristics. Furthermore, we found that government payments are likely responsible for these increases in farmland prices. Financial assistance easing the economic burdens of the agricultural sector can also stabilize farmland prices.

Keywords: farmland prices; administrative data; COVID-19; government payments

Citation: Lee, B.; Cheng, P.-Y.; Sun, L.-C.; Hsieh, Y.-T.; Chang, H.-H. Does COVID-19 Affect Farmland Prices? How and Why? *Agriculture* **2022**, *12*, 2163. https://doi.org/10.3390/agriculture12122163

Academic Editor: Sanzidur Rahman

Received: 31 October 2022
Accepted: 12 December 2022
Published: 15 December 2022

1. Introduction

COVID-19 has profoundly impacted the global economy, slashing economic output by USD 8.5 trillion since 2020 [1]. These changes in economic output have also affected other aspects of human society. The fast-growing literature has examined the impacts of COVID-19 on environmental indicators [2], transportation patterns [3], and the utilization of urban parks [4]. This literature also extends to the agricultural sector. For example, Beckman and Countryman [5] found that agricultural shocks attributable to COVID-19 had disproportionately large impacts on the gross domestic product of the United States. Charlton [6] found that agricultural supply chains have been subjected to increased labor-related input costs as outbreaks spread among agricultural workers at their worksites. Arita et al. [7] suggested that COVID-19 reduced global agricultural trade by 5 to 10%, with these losses being pronounced in commodity markets.

Although this broader literature has considered the impacts of COVID-19 on the agricultural sector, most of these studies only examined macroeconomic outcomes specified at the aggregate level, including agricultural production and agricultural trade. These studies may not have fully identified the distributional impact of COVID-19 on the agricultural sector because of their emphasis on the larger components of agricultural systems. Agricultural indicators are particularly salient for farmers reliant on agricultural production for their livelihoods, but substantially less evidence exists on the impacts of COVID-19 with respect to agricultural indicators specified at the individual level.

Farmland prices are an important indicator of farm well-being because farmland represents both an asset and production input. Indeed, farm real estate constitutes up to 80% of the total value of all farm assets and is used as the primary source of collateral for agricultural loans in the USA [8]. However, the causal effect of COVID-19 on farmland

prices has merely been subject to speculation in government reports. Following the onset of COVID-19 in the USA, agricultural professionals, including agricultural lenders, farm managers, and farm realtors, expected declines in farmland prices for the following 18 months in Iowa [9]. Specifically, they cited lower commodity prices and uncertainty in agricultural trade regarding a reduction in economic returns from agriculture, which are subsequently capitalized into farmland prices. However, several states in the USA reported that farmland prices had increased [10]. These conflicting results suggest that the causal effect of COVID-19 on farmland prices has not been identified or understood. Furthermore, the mechanism responsible for this relationship remains unclear.

This study provides quantitative evidence of the causal effect of COVID-19 on farmland prices using population-based data on farmland transactions. We also take another step towards fully estimating the impact of COVID-19 on farmland prices by empirically testing the mechanism behind this relationship. We use data on farmland prices provided by the Actual Price Registration System (APRS) in Taiwan, which is an important economic indicator for farmers on the island. This dataset records the day, month, and year of farmland transactions, allowing for comparisons of farmland prices before and after the onset of COVID-19 in Taiwan. The main result shows that COVID-19 increased farmland prices by 5.1%, ceteris paribus. A heterogeneity analysis further suggests that these increases are more pronounced for rural farmland. Finally, an analysis of the mechanism shows that government payments are likely responsible for these increases in farmland prices.

This study contributes to the burgeoning research on COVID-19 and the agricultural sector across several fronts. First, this study provides quantitative evidence on the causal effect of COVID-19 on farmland prices using quasi-experimental research methods. Lawley [11] and Lawley [12] discussed the potential mechanisms through which COVID-19 impacted farmland prices and examined this relationship in Canada. Using aggregate quarterly estimates of farmland values with quantile regression, the farmland sold in the first six months of 2020 had higher sales prices of 2.3% in Manitoba, Canada. The author interpreted these results as correlations [11,12]. In contrast, this study applies the difference-in-differences (DiD) method to identify the causal effect of COVID-19 on farmland prices. The DiD method compares outcomes between farmland prices for treatment and control groups before and after the first confirmed cases of COVID-19 in Taiwan. Thus, the estimates presented in this study can be interpreted as causal effects rather than correlations.

Second, this study uses population-based data on farmland transactions. Zhang and Duffy [9] found that COVID-19 was associated with a 1.7% increase in farmland prices using county-level estimates of farmland prices in Iowa. Oppendahl [10] suggested that COVID-19 was associated with a 6% increase in farmland prices using state-level data in the Midwestern United States (Iowa, Illinois, Indiana, Michigan, and Wisconsin). A limitation of these descriptive studies included their reliance on county- or state-level averages of farmland prices, rendering them unable to account for the parcel-level characteristics of farmland. We use population-based data on farmland transactions from the Ministry of Interior in Taiwan, allowing for comprehensive analyses with precisely estimated results. These population-based data also allow us to conduct a heterogeneity analysis based on whether the farmland was sold in rural or urban areas. We also use actual sales prices of farmland transactions provided by the Taiwanese government, avoiding the measurement errors stemming from self-reported values from buyers and sellers [13].

Finally, this study empirically tests the mechanism through which COVID-19 impacts farmland prices in Taiwan. This analysis of the mechanism is crucial for formulating public policy related to farmers and COVID-19. Prior studies in other countries hypothesized that the positive correlation between COVID-19 and farmland prices was largely caused by macroeconomic conditions. For example, Zhang [14] suggested that low interest rates were responsible for increased farmland prices because lower interest rates reduced interest expenses for farmers, supporting farm profitability in the USA. However, we still found that COVID-19 increased farmland prices in Taiwan, even after controlling for macroeconomic conditions, including interest rates and parcel-level farmland characteristics. We found

that the effect of COVID-19 on farmland prices is not completely driven by macroeconomic conditions. Rather, we found that government payments provided to the agricultural sector are responsible for these increases in farmland prices during the COVID-19 period.

2. Government Payments to the Agricultural Sector and COVID-19 in Taiwan

Taiwan provides government payments to farmers and farms to cope with the risks associated with agricultural production, including natural disasters and supply chain concerns. The primary basis of these government payments includes 'policy-based agricultural product loans', where the Bureau of Agricultural Finance (BOAF) provides no-interest loans to farmers and farms under the Agricultural Finance Act [15].

The main purpose of these government payments is twofold: First, government payments directly support farmers and farms. These government payments could be spent on (1) agricultural machinery, (2) agricultural operations and production, and (3) farm operations and production. Second, government payments directly support the farmland market. The BOAF injects capital into the farmland market through these government payments to individuals interested in purchasing farmland, including young and middle-aged farmers and farmers expanding the size of their farm. Farmers paying off mortgages can also receive government payments [15].

Since the 'policy-based agricultural product loans' under the Agricultural Finance Act were designed to reduce the uncertainties associated with agricultural production, COVID-19 exponentially increased the amount of government payments provided under the Agricultural Finance Act. Thus, the BOAF also used government payments to provide economic support to the agricultural sector and the farmland market in response to COVID-19 in Taiwan.

3. Data

3.1. Data on Farmland Transactions

The Actual Price Registration System (APRS) provides data on farmland transactions in Taiwan. The APRS was established in December 2011 under the Ministry of Interior. The APRS records the sales prices of property transactions sold by property owners. By law, property owners must report the sale of their property within 14 days or receive fines of up to TWD 300,000 [16]. The APRS includes administrative records on the sales prices of properties along with their physical characteristics. The administrative records also include the time (day, month, and year) of property transactions. Thus, the APRS is the most important source of information for understanding changes in the economic trends of property transactions in Taiwan. Previous studies have also used the APRS to analyze the farmland and real estate markets in Taiwan [16,17]. The sample used in this study is based on the population of farmland transactions recorded by the APRS. It includes all of the farmlands sold between 1 January and 30 September in 2017, 2018, 2019, and 2020. In total, 51,624 parcels of farmland were sold during these 36 months, of which, 37,543 were sold in 2017, 2018, and 2019, and 14,081 parcels were sold in 2020.

Figure 1 shows the monthly averages of farmland prices from the years of 2017 to 2019 and 2020. The dotted line representing the monthly average of farmland prices from the years of 2017 to 2019 shows that farmland prices were relatively constant at TWD 6000/m^2. In contrast, the monthly averages of farmland prices in 2020 were higher, ranging from TWD 6899/m^2 to TWD 10,775/m^2. This figure provides a snapshot of the evidence indicating that COVID-19 increased farmland prices in Taiwan, although quasi-experimental research methods are necessary to derive causal estimates.

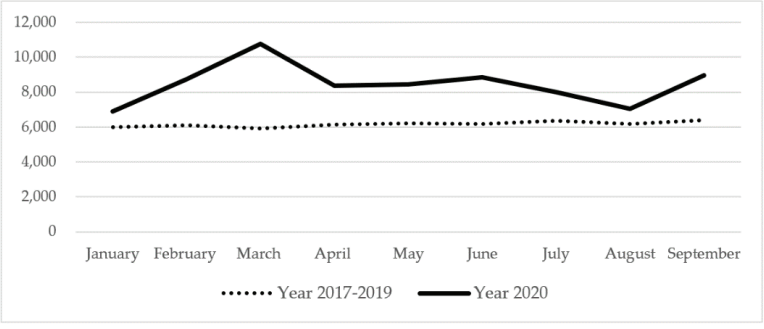

Figure 1. Monthly average farmland prices over time. Note: the Y-axis is farmland price (TWD/m^2), and the X-axis is an indicator of month. Data are drawn from the Actual Price Registration System managed by the Ministry of Interior in Taiwan. The years of 2017 to 2019 report the average values of farmland prices for these three years, while the year of 2020 reports the averages for 2020.

3.2. Data on Agricultural, Environmental, and Geographic Characteristics

The hedonic price theory indicates that the price of a product is determined by its attributes or characteristics [18]. In the case of farmland, the price of farmland is associated with its agricultural, geographic, and environmental characteristics because these factors affect the economic returns from agriculture [19]. Geographic maps containing information on the spatial distribution of agricultural facilities, agricultural zoning, and farmland productivity provided by the Council of Agriculture (CoA) are merged with the data on farmland transactions from the APRS. Two variables are used to measure the closest distance of each parcel of farmland to the nearest irrigation facility: a dummy variable, which indicates whether the farmland is in a major crop production zone, and a continuous variable of land productivity, which is indexed from 1 to 11. Higher scores indicate better land quality.

The previous literature suggests that farmland prices are not only determined by variables related to the economic returns from agriculture but also to the convenience of transportation and the potential for urban development [20]. We specify three variables to measure the convenience of transportation and the potential for urban development for each parcel of transacted farmland: the closest distance to the nearest highway, major road, and railroad in Taiwan.

3.3. Data on COVID-19

The Centers for Disease Control (CDC) provide data on COVID-19 cases in Taiwan. Specifically, we collect the daily number of confirmed cases of COVID-19 from 22 January to 30 September 2020. Next, we define two variables to quantify the spread of COVID-19. The first variable is a binary indicator defining the incidence of COVID-19. The value of this dummy variable is equal to one if the parcel of farmland was transacted after 22 January 2020 (the date of the first confirmed case of COVID-19 in Taiwan) and zero otherwise. The second variable is a continuous variable for the number of cumulative confirmed cases of COVID-19 for each day of the study period. These two variables measure the extensive and intensive spread of COVID-19 in Taiwan. In addition to these two variables, we specify another variable measuring web searches related to COVID-19 from Google Trends. We extract an index measuring the popularity of web searches for 'COVID-19' or 'Coronavirus' during each week of the treatment period (the COVID-19 period). This variable measures the general interest in COVID-19 among the public in Taiwan, given that individuals may not immediately become aware of additional cases of the disease.

3.4. Data on Government Payments and Macroeconomic Conditions

Other explanatory variables specified in this study include data on macroeconomic conditions and government payments provided to the agricultural sector. The Bureau of Agricultural Finance (BOAF) provides data on the total amount of government payments issued to the agricultural sector aggregated to each township at the monthly level from 2017 to 2020. This variable proxies for the total amount of government payments provided to the agricultural sector because the majority of the support provided by the BOAF included these financial instruments [15].

We specify three variables to reflect macroeconomic conditions across time in Taiwan. These three variables are drawn from official statistics reported by the Ministry of Economic Affairs (MOEA). The first variable is the monthly food price index between 2017 and 2020. The second and third variables are the monthly interest rates and the monthly stock market price index between 2017 and 2020. These three variables are merged by month and year with the data on farmland transactions.

3.5. Sample Statistics of the Selected Variables

Table 1 reports the sample statistics of farmland prices. Panel A of Table 1 shows the sample statistics of farmland prices before and after the first confirmed cases of COVID-19 were reported in Taiwan. We average the monthly farmland prices from 2017 to 2019 and define these years as the Pre-COVID-19 period in Taiwan. The average farmland prices were 5989 TWD/m^2 in January, peaking at 6218 TWD/m^2 in May from 2017 to 2019. The monthly numbers of transactions were relatively consistent, ranging from 1382 to 1286 transactions for the months of January and September from 2017 to 2019. Next, we average the monthly farmland prices in 2020 and define this year as the COVID-19 period in Taiwan. The average farmland prices were 6899 TWD/m^2 in January 2020, peaking at 10775 TWD/m^2 in March 2020.

Table 1. Sample statistics of farmland prices over time.

	Panel A. Farmland Transaction Data				**Panel B. COVID-19 Data**	
	Farmland Prices (TWD/m^2)		**Number of Transactions**		**Cumulated Cases**	**Google Search #**
Year Month	2020 (A)	2017–2019 (B)	2020 (C)	2017–2019 (D)	2020 (E)	2020 (F)
January	6899	5989	1129	1382	10	48
February	8725	6099	1556	1004	39	98
March	10,775	5903	2040	1572	322	100
April	8383	6151	1614	1429	429	63
May	8446	6218	1765	1575	442	22
June	8846	6187	1695	1461	447	14
July	8010	6352	1503	1464	467	12
August	7054	6167	1299	1341	488	12
September	8953	6389	1479	1286	514	8

Note: The average value between 2017 and 2019 is reported. # The peak in the number of keyword searches for COVID-19 in March 2020 is set to 100. Data are drawn from the administrative profile of farmland prices in Taiwan. Years 2017–2019 report the average values between 2017 and 2019. Year 2020 reports the average value in 2020.

Table 1 also reports the number of cumulative confirmed cases of COVID-19 and Google Searches related to COVID-19 in Taiwan. Panel B of Table 1 shows this distribution. At the end of January 2020, there were 10 cumulative confirmed cases of COVID-19 in Taiwan. This grew to 322 cumulative confirmed cases in March 2020, until gradually receding to 514 cumulative confirmed cases in September 2020. Information on COVID-19 was widely searched for in January 2020, peaking in March 2020. Google Searches related to COVID-19 decreased after March 2020, corresponding to the months where the community spread of COVID-19 was rather minimal in Taiwan.

Table 2 reports the summary statistics of the selected variables. We present the sample statistics based on the full sample and the prices of farmland sold after 22 January 2020 (Post = 1 & Treat = 1), after 22 January from 2017 to 2019 (Post = 0 & Treat = 1), between 1 January and 22 January 2020 (Post = 1 & Treat = 0), and between 1 January and 22 January for 2017, 2018, and 2019 (Post = 0 & Treat = 0). On average, farmland prices were TWD 6930/m^2 for the entire sample. After 22 January 2020, farmland prices were TWD 8727/m^2. The average amount of government payments issued to the agricultural sector in each township per year increased to TWD 15.31 million/month compared to TWD 10.32 million/month during other periods of time. Finally, 14.6% of the farmland sold after 22 January 2020 was located in urban areas compared to 24.6% of that sold during other periods of time.

Table 2. Sample statistics of the selected variables.

N*T		Full Sample 51,624		Post = 1 & Treat = 1 13,106		Post = 0 & Treat = 1 34,607		Post = 1 & Treat = 0 975		Post = 0 & Treat = 0 2936	
Variable	**Definition**	**Mean**	**S.D**	**Mean**	**S.D**	**Mean**	**S.D**	**Mean**	**S.D**	**Mean**	**S.D**
Post	If year 2020 (=1).	0.27	0.45	1	0	0	0	1	0	0	0
Treat	If after 22 January (=1).	0.92	0.27	1	0	1	0	0	0	0	0
Price	Price of the transacted parcel of farmland (TWD/m^2).	6830	8753	8727	10,404	6196	8056	7049	8010	5763	7475
Payments	Government payments in the township (TWD million/month).	10.32	14.04	15.31	20.01	8.54	10.72	7.43	9.93	10.02	11.80
Land	Size of the transacted parcel of farmland (1000 m^2).	2.00	2.53	2.03	2.29	1.99	2.62	1.96	2.18	2.00	2.56
Urban	If in an urban area (=1).	0.25	0.43	0.15	0.35	0.28	0.45	0.23	0.42	0.28	0.45
Irrigation	Closest distance to the irrigation facility (m).	0.25	0.51	0.21	0.41	0.27	0.53	0.24	0.44	0.26	0.57
Crop	If in a crop production zone (=1).	0.48	0.50	0.57	0.50	0.45	0.50	0.42	0.49	0.42	0.49
Productivity	Land productivity (1–10). The higher the score, the better the quality.	2.74	1.87	2.55	1.83	2.80	1.87	2.63	1.80	2.83	1.90
Farm association	Closest distance to the nearby farm association (m).	3.03	1.82	3.16	1.79	2.98	1.82	3.07	1.82	3.03	1.84
Railroad	Closest distance to railroad (m).	7.84	6.53	8.28	6.27	7.69	6.63	7.60	6.26	7.72	6.56
Highway	Closest distance to highway (=1).	7.96	12.34	7.37	11.59	8.14	12.57	7.74	12.02	8.42	12.94
Road	Closest distance to major road (=1).	1.55	1.64	1.54	1.55	1.55	1.67	1.49	1.50	1.62	1.68
D_COVID	If during COVID-19 period (=1).	0.25	0.44	1	0	0	0	0	0	0	0
COVID_case	Number of cumulated confirmed cases of COVID-19 per day.	36.50	117.62	143.78	197.67	0	0	0	0	0	0
COVID_search	Google Trends Search Index for COVID-19 per month.	12.00	27.28	43.70	37.65	0	0	48	0	0	0
Food price	Food price index in month.	96.80	3.12	95.93	2.75	96.97	3.05	103.60	0	96.41	2.84
Interest rate	Average monthly interesting rate.	2.60	0.06	2.52	0.08	2.63	0.00	2.63	0	2.63	0.000
Stock price	Month average stock price index (10,000).	1.07	0.08	1.14	0.09	1.05	0.04	1.20	0	1.00	0.07

4. Methodology

Because COVID-19 was an unexpected exogenous shock to the global economy, prior studies applied the difference-in-difference (DiD) method to estimate the impact of COVID-19 on economic outcomes [21,22]. In line with these studies, we specify the DiD method to identify the causal effect of COVID-19 on farmland prices in Taiwan.

The DiD method compares the differences in outcomes between treatment and control groups before and after the occurrence of an event or intervention. In this study, the control

group is defined as the parcels of farmland sold between 1 January and 21 January of each respective year because the first confirmed case of COVID-19 was officially reported on 22 January 2020 in Taiwan. Similarly, the treatment group is defined as the parcels of farmland sold after 22 January of each respective year. Next, we define the time period before and after the occurrence of an event or intervention. Farmland sold in 2017, 2018, and 2019 are defined as the Pre-COVID-19 period, while those sold in 2020 are defined as the Post-COVID-19 period. The generalized version of the model for the farmland price equations is specified as follows:

$$logP_{ijt} = \alpha + \gamma \times COVID_t + \beta' X_{ijt} + = \rho \times Treat_{it} + u_j + u_t + \varepsilon_{ijt} \quad (1)$$

where $logP_{ijt}$ is the logged value of the farmland price for the ith parcel of farmland located in township j transacted on day t. $COVID_t$ is a variable measuring the spread of COVID-19 in Taiwan. This includes the binary indicator defining the incidence of COVID-19 and the other two continuous variables defining the number of cumulative confirmed cases of COVID-19 for each day of the study period and the intensity of web searches related to COVID-19 on Google Trends. X_{ijt} is a vector of explanatory variables associated with farmland prices, and $Treat_{it}$ is a binary indicator for the treatment group. u_j and u_t are township and time fixed effects. The time fixed effects include month and year fixed effects to account for the monthly and yearly trends of farmland prices across townships. α, γ, β, ρ are the estimated parameters. The standard errors of the coefficients are clustered at the township level.

In Equation (1), the parameter γ quantifies the average treatment effect on the treated (ATT) of COVID-19 on farmland prices in Taiwan. The ATT estimator compares farmland prices before and after the first confirmed cases of COVID-19 in Taiwan across otherwise similar times after controlling for the explanatory variables associated with farmland prices. When the binary indicator measuring the incidence of COVID-19 is used, γ measures the change in percent in farmland prices before and after the first case of COVID-19 was confirmed in Taiwan on 22 January 2020. When the two continuous variables are used, γ measures the change in percent in farmland prices in response to an additional cumulative confirmed case of COVID-19 or an increase in Google Searches. We estimate Equation (1) using the fixed-effect models, and the standard errors of the parameters are clustered at the township level.

5. Empirical Results

5.1. Main Findings

Table 3 reports the main results of the farmland price equations. Model A reports the extensive effects of COVID-19 on farmland prices based on the binary indicator measuring the spread of COVID-19. Models B and C report the intensive effects of COVID-19 using the continuous variables on an additional cumulative confirmed case and web searches on Google Trends related to COVID-19. The other explanatory variables specified in the farmland price equations are listed in Table 2.

Model A of Table 3 captures the impact of COVID-19 on farmland prices after controlling for other explanatory variables of interest. The onset of COVID-19 increased farmland prices by 5.1%, ceteris paribus. Model B of Table 3 reports the estimates when the number of cumulative confirmed cases of COVID-19 is specified as the variable measuring the spread of COVID-19. An additional increase in the number of cumulative confirmed cases of COVID-19 increased farmland prices by 0.038%, ceteris paribus. Model C reports the estimates using web searches related to COVID-19 on Google Trends. An additional increase in web searches related to COVID-19 increased farmland prices by 0.086%, ceteris paribus. These results indicate that COVID-19 increased farmland prices across all three specifications of the variable measuring the spread of COVID-19 in Taiwan.

Table 3. Estimation of the farmland price equations (in log).

	Model A		Model B		Model C	
Variable	**Coefficient**	**S.E**	**Coefficient**	**S.E**	**Coefficient**	**S.E**
D_COVID	0.051 **	0.018				
COVID_case/1000			0.383 **	0.151		
COVID_search/1000					0.866 *	0.464
Treat	−0.037	0.021	−0.021	0.022	−0.018	0.022
Land	−0.019 ***	0.002	−0.019 ***	0.002	−0.019 ***	0.002
Urban	0.514 ***	0.010	0.509 ***	0.010	0.508 ***	0.010
Irrigation	0.013	0.015	0.012	0.015	0.012	0.015
Crop	0.095 ***	0.005	0.099 ***	0.005	0.101 ***	0.005
Productivity	0.025 ***	0.002	0.025 ***	0.002	0.025 ***	0.002
Farm association	−0.049 ***	0.002	−0.049 ***	0.002	−0.049 ***	0.002
Railroad	−0.013 ***	0.001	−0.013 ***	0.001	−0.013 ***	0.001
Highway	−0.013 ***	0.002	−0.013 ***	0.002	−0.012 ***	0.002
Road	−0.031 ***	0.003	−0.031 ***	0.003	−0.031 ***	0.003
Food Price	0.004	0.003	0.004	0.003	0.004	0.003
Interest rate	−0.232 **	0.115	−0.299 **	0.115	−0.603 ***	0.222
Stock price	−0.220 *	0.114	−0.268 **	0.112	−0.216 *	0.112
Constant	8.341 ***	0.020	8.357 ***	0.020	8.339 ***	0.020
Control for years	Yes		Yes		Yes	
Control for months	Yes		Yes		Yes	
Control townships	Yes		Yes		Yes	
Adjusted R^2	0.773		0.773		0.773	
N	51,624		51,624		51,624	

Note: ***, **, and * indicate statistical significance at 1%, 5%, and 10% levels, respectively. Standard errors are clustered in townships.

The models also control for farmland characteristics and environmental characteristics. The point estimates of these controls are practically identical in statistical significance and magnitude across all three models in Table 3. We discuss these point estimates using the results from Model A in Table 3. Farmland located in urban areas had higher sales prices of 51.4%. This premium is driven by speculation on behalf of real estate investors for converting farmland into residential housing [20]. Agricultural productivity increased farmland prices, as a one-point increase in this index increased sales prices by 2.5%. Size decreased farmland prices. Every 1000 m^2 increase in the size of farmland reduced sales prices by 1.9%. Greater distances away from farmer's associations, railroads, highways, and roads reduced farmland prices.

We also control for macroeconomic conditions in the farmland price equations. Specifically, we focus on food prices, interest rates, and stock prices because government reports have speculated that the positive correlation between COVID-19 and farmland prices are largely driven by these variables. The results from Model A in Table 3 show that interest rates and stock prices are positively associated with farmland prices in Taiwan. However, after controlling for these macroeconomic variables in the farmland price equations, the coefficient of the variable measuring the spread of COVID-19 remained statistically significant and substantial in magnitude. This provides evidence that macroeconomic conditions do not solely explain the causal effect of COVID-19 on farmland prices.

5.2. Urban versus Rural Areas

Previous studies have suggested that the primary purpose of farmland use differs between urban and rural areas. Plantinga and Miller [19] observed that urban farmland is purchased as a financial investment, while rural farmland is more likely to be purchased for agricultural use. Subsequently, the difference in the primary purpose of farmland use could possibly result in differential impacts of COVID-19 on farmland prices across urban and rural areas. In this section, we conduct a heterogeneity analysis to test this hypothesis.

Panel A of Table 4 presents the results for the farmland price equations using the subsample of farmland sold in urban areas. As reported, COVID-19 caused urban farmland prices to increase by 3.8%, and an increase in the number of cumulative confirmed cases of COVID-19 increased urban farmland prices by 0.028%, ceteris paribus. Moreover, an increase in the number of web searches related to COVID-19 increased urban farmland prices by 0.061%.

Table 4. Estimation of the farmland price equations.

	Panel A. Urban Farmland					
Key Variable	**Coefficient**	**S.E**	**Coefficient**	**S.E**	**Coefficient**	**S.E**
D_COVID	0.038 *	0.021				
COVID_case/1000			0.279 *	0.141		
COVID_search/1000					0.613 *	0.316
Other variables	Yes		Yes		Yes	
Adjusted R^2	0.071		0.071		0.071	
N	12,683		12,683		12,683	
	Panel B. Rural farmland					
Key variable	Coefficient	S.E	Coefficient	S.E	Coefficient	S.E
D_COVID	0.063 ***	0.018				
COVID_case/1000			0.490 **	0.231		
COVID_search/1000					0.913 *	0.528
Other variables	Yes		Yes		Yes	
Adjusted R^2	0.781		0.780		0.781	
N	38,919		38,919		38,919	

Note: The dependent variable of the farmland price is in logarithm. The list of the other control variables, including the township fixed effects, can be found in Table 3. ***, **, and * indicate statistical significance at 1%, 5%, and 10% levels, respectively. Standard errors are clustered in townships.

Panel B of Table 4 presents the results for the farmland price equations using the subsample of farmland sold in rural areas. It is evident that the onset of COVID-19 caused rural farmland prices to increase by 6.3%. An additional increase in the number of cumulative confirmed cases of COVID-19 increased rural farmland prices by 0.049%. Finally, an additional increase in web searches related to COVID-19 increased rural farmland prices by 0.091%. The heterogeneity analysis shows that COVID-19 caused larger increases in farmland prices in rural areas.

5.3. Robustness Checks of the Main Findings

We conduct a placebo test to confirm the robustness of the main results. We estimate the model using hypothetical years for the onset of COVID-19 in Taiwan in 2019, 2018, and 2017. Because the first cases of COVID-19 were confirmed in Taiwan on 22 January 2020, there should be an insignificant result when estimating the DiD estimators using these falsified treatment groups. Table 5 reports the results of the placebo test. The results show that COVID-19 had statistically insignificant effects on farmland prices in 2019, 2018, and 2018, suggesting that the main results are not caused by spurious correlations.

Table 5. Falsification test of the DiD model.

Hypothetical Shock	**Year 2019**		**Year 2018**		**Year 2017**	
Variable	**Coefficient**	**S.E**	**Coefficient**	**S.E**	**Coefficient**	**S.E**
D_COVID	0.003	0.012	−0.012	0.022	0.019	0.022
Treat	−0.033	0.220	−0.025	0.020	−0.028	0.020
Other variables [#]	Yes		Yes		Yes	
Adjusted R^2	0.751		0.751		0.751	

Note: We use the data in the Pre-COVID-19 period for 2017, 201,8 and 2019. [#] The list of the other control variables, including the township fixed effects, can be found in Table 3. Standard errors are clustered in townships.

5.4. The Impact of COVID-19 on Government Payments

The next question of interest includes understanding the mechanism responsible for the impact of COVID-19 on farmland prices in Taiwan. We propose that government payments provided to individual farmers or farms can help to explain the main findings. The link between government payments and farmland prices has been widely documented in the agricultural economics and land economics literature, known as the capitalization effect [23]. In their review article, Latrouffe and Mouel [24] found that government payments were capitalized into farmland prices because farmers considered these funds akin to other sources of farm income, including the economic returns from agriculture.

To test whether government payments to the agricultural sector is the mechanism through which COVID-19 increases farmland prices in Taiwan, we estimate another DiD model with the dependent variable specified as the monthly amount of government payments that each township received from the BOAF. The intuition behind the government payments equation is that COVID-19 may correspond to increases in government payments to the agricultural sector, which could be capitalized into farmland prices in Taiwan. Table 6 reports the results of the government payments equation. The results reported in Model A show that COVID-19 increased government payments to the agricultural sector at the township level by TWD 2.74 million, ceteris paribus. An additional cumulative confirmed case of COVID-19 increased government payments to the agricultural sector at the township level by TWD 0.5 million. An increase in the number of web searches related to COVID-19 increased government payments to the agricultural sector by TWD 0.03 million. These results indicate that COVID-19 increased the amount of government payments that the agricultural sector received in Taiwan.

Table 6. Estimation of the government payments equation.

	Model A		**Model B**		**Model C**	
Key Variable	**Coef.**	**S.E**	**Coef.**	**S.E**	**Coef.**	**S.E**
D_COVID	2.7462 ***	0.5472				
COVID_case			0.0005 ***	0.0008		
COVID_search					0.0335 ***	0.0118
Other variables #	Yes		Yes		Yes	
Adjusted R^2	0.477		0.476		0.476	
N	51,624		51,624		51,624	

Note: # The list of the other control variables, including the township fixed effects, can be found in Table 3. *** indicates statistical significance at 1%. Standard errors are clustered in townships.

6. Discussions and Conclusions

This study examined the causal effect of COVID-19 on farmland prices in Taiwan. COVID-19 caused farmland prices to increase by 5.1%. An increase in the number of cumulative confirmed cases of COVID-19 also increased farmland prices. Finally, we empirically tested the mechanism through which COVID-19 increased farmland prices. The payments provided by the Taiwanese government to financially support the agricultural sector provided are responsible for these increases.

We found that interest rates are not the sole determinant of changes in farmland prices caused by COVID-19. Recall that the farmland price equations show that, even after controlling for macroeconomic conditions, such as food prices, interest rates, and stock prices, COVID-19 significantly increased farmland prices. Previous studies concluded that the relationship of COVID-19 with farmland prices depends on the direction and magnitude of macroeconomic conditions, particularly interest rates [11]. Thus, this study shows that government payments also impact farmland prices, consistent with more recent descriptive studies where ad hoc government payments, such as the Coronavirus Food Assistance Program, were found to be correlated with farmland prices in the United States [14].

The heterogeneity analysis shows that this effect is more pronounced for rural farmland. The Bureau of Agricultural Finance (BOAF) provided government payments only

to the agricultural industry, where they must be used for agricultural purposes. The guidelines of these government payments are that they must be used to directly support agricultural operations and production for the agricultural sector or individuals interested in purchasing farmland for agriculture. Fairbairn [25] found that farmland in urban areas is more likely to be used by part-time farmers because they also use farmland as an asset investment. The heterogeneity analysis reflects the possibility that part-time farmers are less likely to purchase urban farmland as an investment due to the economic uncertainty caused by COVID-19. Subsequently, government payments have larger effects on rural farmland where agriculture is more likely to be its primary use [19].

This study has several policy implications. Anecdotal evidence suggests that emerging variants such as Omicron BA.2 will continue to impact the operations and production of the agricultural sector, subsequently affecting farm incomes [26]. As the pandemic continues, understanding the relationship between COVID-19 and farmland prices will remain important. Relatedly, while the previous literature has examined how farmland prices are impacted by exogeneous shocks, such as commodity prices for corn, these results are applicable for understanding how farmland prices will respond to exogeneous shocks related and non-related to COVID-19 [27].

Finally, this study provides insight into the economic instruments that policymakers can use to stabilize the farmland market. Many countries have implemented measures to support the agricultural sector in response to COVID-19. The USDA developed and implemented the Coronavirus Food Assistance Program and the USDA Pandemic Assistance to Producers to support producers impacted by market disruptions. Similarly, the Agricultural Finance Act used by the BOAF in Taiwan also reduced the economic burdens of the agricultural sector, subsidizing agricultural and farm operations and production. Thus, this study suggests that policymakers should consider government payments to the agricultural sector as a potential instrument to stabilize farmland markets in the future.

Although this study quantified the causal effect of COVID-19 on farmland prices, several caveats remain. First, we could not examine the impact of COVID-19 on other individual farm-level outcomes, such as farm profits. Second, we could not examine the impact of COVID-19 on different types of farms, such as fruit, vegetable, and rice farms. Third, we only investigated the causal effect of COVID-19 on farmland prices over nine months. Fourth, the data only include farmland transacted on the farmland market in Taiwan. Finally, our results may not be valid in the presence of potential spillover effects. That is, farmland sold in response to COVID-19 could affect the price of other parcels. Regardless of these potential drawbacks, the analytical framework used in this study can also be used to investigate the impact of COVID-19 on farmland prices in other countries. Moreover, given the global spread of COVID-19, these results provide implications for the farmland market in other countries.

Author Contributions: Conceptualization, all authors; methodology, B.L., L.-C.S., and P.-Y.C.; software, Y.-T.H.; validation, H.-H.C.; formal analysis, P.-Y.C., L.-C.S., and Y.-T.H.; writing—original draft preparation, B.L. and H.-H.C.; writing—review and editing, B.L. and H.-H.C.; funding acquisition, P.-Y.C. and L.-C.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Readers who are interested in the dataset can contact the Council of Agriculture for approval.

Acknowledgments: The authors thank the Council of Agriculture for making the data available. The findings of this paper do not reflect the view of the institute. The authors are responsible for any errors.

Conflicts of Interest: The authors declare no conflict of interest.

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Does Digital Finance Increase Relatively Large-Scale Farmers' Agricultural Income through the Allocation of Production Factors? Evidence from China

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Abstract: The inclusiveness of digital finance brings new opportunities for the development of agriculture, rural areas, and farmers. The purpose of this paper is to clarify how digital finance influences relatively large-scale farmers' agricultural income. Based on survey data from rural China, this paper systematically investigates the impact of digital finance on relatively large-scale farmers' agricultural income using the Multiple Intermediary Effect Model. The findings of this study reveal that digital finance has a substantial positive influence on relatively large-scale farmers' agricultural income, and this effect still exists after considering endogeneity and a series of robustness tests. Further mechanism analyses suggest that agricultural capital, agricultural land, and agricultural workforce play a partial mediating role between digital finance and agricultural income. The development of digital finance has a positive impact on improving agricultural capital investment and land transfer, while it has a negative impact on agricultural workforce. Moreover, the results of the grouping estimation show that digital finance has more significant effects on agricultural income for economic crops and farmers who received agricultural skills training and agricultural services. These results provide a micro explanation to promote relatively large-scale farmers' agricultural income with the accelerated popularization of digital finance, urgently needed for most emerging countries seeking high-quality rural development.

Keywords: digital finance; relatively large-scale farmers; agricultural income; agricultural capital; agricultural workforce; agricultural land rent-in; China

Citation: Song, K.; Tang, Y.; Zang, D.; Guo, H.; Kong, W. Does Digital Finance Increase Relatively Large-Scale Farmers' Agricultural Income through the Allocation of Production Factors? Evidence from China. *Agriculture* **2022**, *12*, 1915. https://doi.org/10.3390/agriculture12111915

Academic Editor: Sanzidur Rahman

Received: 17 October 2022
Accepted: 10 November 2022
Published: 14 November 2022

1. Introduction

The development of agriculture is moving in the direction of scale, modernization, and industrialization. With the traditional small-scale and loose management farmers gradually turning to the new agricultural operation system, large-scale farmers are becoming an important subject of modern agricultural development. Promoting the income of large-scale farmers is conducive to the development of agricultural modernization and realizing rural revitalization. There are differences between the income structure of large-scale farmers and traditional small farmers. Small farmers mostly operate part-time, while large-scale farmers mostly take agricultural income as the main source of income [1], and it is necessary to pay attention to agricultural income to realize the income increase of large-scale farmers.

Agricultural credit significantly impacts the development of agriculture. Compared to the smallholders, the relatively large-scale farmers often need more funds for agricultural production. However, due to asymmetric information, high transaction costs, and lack of adequate collateral [2,3], there exist long-term threshold effects, financial exclusion, "mission drift," and "elite capture" in the rural financial market [4–6]. The development of inclusive finance has alleviated the above dilemma [7]. Many studies have found that inclusive rural finance significantly affects agriculture production, farmers' income, and welfare and can improve income inequality among farmers [8–11].

Digital finance is a product of the deep integration of traditional finance and Internet information technology, and it is a new business model in which traditional financial institutions and internet companies use digital technology to realize financing, payment, and investment [12]. One World Bank report shows that the application of digital technology has opened up new opportunities for rural areas through financial services [13]. Digital finance makes up for the shortcomings of traditional finance and is regarded as a low-cost and convenient financial service access for farmers [14]. China's financial industry has fully entered the digital finance era [15]. Digital finance breaks geographical restrictions to improve lending convenience [16,17]. Digital finance improves financial inclusion and stability [18], changes the traditional financial sector, promotes the quality and diversity of banking services [19], increases the efficiency of the financial market [20], and expands credit boundaries [21] by reducing information collection costs and transaction costs. Regarding the impact on the economy and society, digital finance helps improve residents' income, reduce the poverty rate, reduce income inequality, and narrow the urban–rural gap [22–24]. Researchers thought that digital finance can affordably improve financial services accession for rural households without access to financial services and can be regarded as a powerful tool to achieve inclusive finance [18,25–27].

The existing literature concerning the impact of digital finance on agriculture remains in its infancy, and conclusions conflict; currently, according to the 2017 China rural Internet application report, the promotion effect on agricultural production remains limited overall with rapid internalization in China's rural areas. Liu et al. also believed that inclusive digital finance significantly affects the efficiency of non-agricultural economic activities rather than agricultural production; it can significantly encourage rural households to reduce agricultural production [28]. However, Zhao et al. found that digital finance alleviates their credit constraints, which may exert an impact on the adoption of sustainable agriculture practices [29]. Sustainable agriculture is conducive to increasing agricultural productivity and income [30]. Thus, digital finance's impact on agricultural income and its mechanism is worth exploring. Digital finance has developed rapidly in China and has become an essential part of China's financial system. In a short period of more than ten years, with payment as the core, China has taken the lead on a global scale scope for digital finance development. Based on the "Digital Finance Index" released by the research group of the Digital Finance Research Center of Peking University, each province's average digital financial inclusion index has risen at rapid growth, from 40 to 341.22, during the period between 2011 and 2020. The number of Internet users in the rural area of China reached 2.84 hundred million. The data released by the China Internet Network Information Center(CNNIC) shows the 5G service coverage rate of administrative villages has reached 80% by the end of 2021. Nearly all rural residents have access to relatively stable, high-speed mobile network services. Thus, China is a compelling setting to explore this issue in-depth.

The improvement of agricultural performance results from rationalization and advancing efficiency in agriculture production factor allocation [31,32]. To the best of our knowledge, digital finance is conducive to collect information about agricultural production processes, address information asymmetries, and provide farmers with free and faster access to credit. Purchasing medical, pension, and agricultural insurance online helps to protect the physical and mental health, enhance the ability to resist risk, improve labor productivity, and increase farmers' labor supply. Digital finance is beneficial to improving financial literacy, which can promote agricultural land rent-in. The above analysis appears to change the constraints of initial agricultural production factors' endowment, further affecting the agricultural production decisions of farmers. Is this judgment accurate? If so, how? Thus, based on the logic of "digital finance-factor allocation-agricultural income", we bring agricultural capital, agricultural land transfer, and agricultural workforce supply into a unified analysis framework. This study elucidates the mechanism of allocation of production factors through which digital finance affects agriculture income from theoretical and empirical perspectives based on the China Labor Force Dynamics Survey (CLDS) 2016

and 2018. Our analysis enriches the literature in four distinct ways. First, although the relatively large-scale farmers cannot represent the general situation in China, large differences in production and operation between the relatively large-scale farmers and small-scale farmers exist. The share of relatively large-scale farmers is increasing greatly, that is, this group cannot be ignored indeed. This paper focuses on the relatively large-scale farmer. Second, we empirically test that digital finance is essential to improving large-scale farmers' agricultural income. Third, does digital finance impact agricultural income through the allocation of agricultural production factors? For agricultural capital, agricultural workforce, and agricultural land, which production factor plays the stronger mediating role? Last, we contribute to understanding the different impacts of digital finance on agricultural income by highlighting the following aspects: agricultural service, agricultural technical skills training, and crop type. We extend the extant understanding of how digital finance promotes agricultural income.

2. Literature Review and Hypothesis

2.1. Digital Finance, Agriculture, and Agricultural Income

Relying on emerging technologies, such as cloud computing, big data, and block chain [33], digitalization transforms the traditional financial system and spawns new Internet-based financial formats. Digital finance is rooted in widespread financial exclusion and is regarded to have the ability to compensate for traditional financial institutions' disadvantages [34,35]. Scholars performed theoretical exploration in conjunction with e-commerce [36]. They explored the effect of digital finance on new types of agricultural production operation entities [37], agricultural industry chains [38], and P2P online lending [39]. Specifically, the role of digital finance on agricultural income is reflected in the following three aspects:

First, digital finance improves access to credit for large-scale farmers who lacked collateral [40]. Finance improves agricultural production efficiency [41,42]. Large-scale farmers with loans will actively participate in agricultural production and benefit from doing so. Second, digital finance promotes technology innovation [43,44]. New technologies improve agricultural efficiency and output [45]. Modern agriculture depends on continuously increasing efficiency instead of relying on an unlimited expansion of productive factors [46]. Farmers will benefit from adopting new agricultural technology to improve agricultural efficiency. Third, digital finance helps the sales of agricultural products by promoting the development of e-commerce and then affects agricultural income [47]. Based on the "Metcalf law" and "long-tail theory" [48], mobile payment can more accurately match agricultural products with the needs of consumers and develop a broader market. The outbreak of COVID-19 has prompted more consumers to purchase agricultural products online in China [49]. According to the China Agricultural E-Commerce Development Report in 2022, major e-commerce platforms for agricultural products are Alibaba, JD, Meituan, Pinduoduo, TikTok, etc. Digital credit will support relatively large-scale farmers participating in agricultural products e-commerce, remove the geographical restrictions, widen agricultural product sales channels and markets, and increase agricultural income.

Based on the above analysis, we state the Hypothesis 1:

H1. *The development of digital finance can promote relatively large-scale farmers' agricultural income.*

2.2. The Mediating Role of Agricultural Capital, Agricultural Workforce, and Agricultural Land

Digital finance has substantial resource availability and more efficient resource allocation [21,34]. As shown in the above analysis, digital finance influences agricultural capital, agricultural production, and sales of agricultural products. Compared to traditional small-scale farmers, relatively large-scale farmers have comparative advantages in agricultural production; after obtaining financial support, relatively large-scale farmers are more inclined to invest in agricultural production and change the endowment of agricultural production factors. Due to the differences in the nature of agricultural production factors

and their substitutability, the direction and degree of digital finance impacting various agricultural production factors are different. Therefore, we analyze them separately to pave the way for exploring how digital finance impacts agricultural income through the allocation of factors:

In terms of agricultural capital, digital finance helps to develop new technologies and apply new tools, which improve agricultural efficiency and output [45]. In correspondence, farmers' enthusiasm and expected return for agricultural production are greater. Easy accession to credit prompts farmers to invest more in the agricultural field [47]. Especially, mobile payment reduces the transaction cost of agricultural products and expands sales [47], prompting farmers to hire more labor and invest more in farm machinery, pesticides, and fertilizer [50]. Using machinery could increase farmers' income [51]. Additionally, farmers can easily purchase agricultural insurance online. Agricultural insurance is conducive to increasing farmers' input of agricultural production factors [52].

In terms of the agricultural workforce. The development of digital finance has led to economic growth, created more job opportunities, and raised the employment rate and income level of residents [53]. Manyika and other scholars have predicted that the application of digital finance will make a great contribution to the annual GDP growth of emerging economies, and that 95 million jobs will be created by 2025 [34]. Moreover, digital financial can relieve the constraints of insufficient academic education on farmers' entrepreneurial choices and partially replace the tacit knowledge of rural residents, which ultimately enhances the entrepreneurial behavior choices of the farmers [54]. In turn, these returning laborers who start their businesses promote the endogenous development of the local economy, resulting in more non-agricultural jobs.

In terms of agricultural land, the essence of agricultural land transfer is a contractual agreement between the transferee and the transferee. However, the information on the land transfer in rural areas is not smooth, which reduces farmers' willingness to rent in land, increases the transaction cost, and restricts the improvement of the agricultural land transfer system. Digital finance can obtain customer information and credit records more efficiently and accurately through the interaction of big data and digital platforms [33], alleviate the information imbalance between land supplier and demander and get rid of the "free rent" and "acquaintance society" restrictions on rural areas, disseminate financial knowledge, and improve financial literacy, which can promote large-scale farmers to rent the land [55]. Meanwhile, it is more convenient for relatively large-scale farmers to buy agriculture insurance online. Agricultural insurance encourages farmers to consolidate idle, scattered, and abandoned land and put them back into agricultural production [56]. Efficient land transfer can realize the concentration of agricultural land and obtain economies of scale, which is conducive to using advanced technologies and agricultural machinery. By renting-in agricultural land, farmers achieve large-scale operation and greater production efficiency, which has a significant impact on farmers' income [57].

Therefore, we propose the following hypothesis:

H2. *The development of digital finance urges relatively large-scale farmers to invest more in the agricultural field, promoting agricultural income.*

H3. *The development of digital finance promotes the off-farm transfer of agricultural labor and reduces agricultural income.*

H4. *The development of digital finance facilitates agricultural land rent-in and promotes agricultural income.*

3. Research Design

3.1. Data Sources

The household data used in this paper was released by China Labor Dynamics Survey (CLDS) data in 2016 and 2018. The survey was a large-scale comprehensive survey organized by Sun Yat-Sen University. The survey was carried out in the form of face-to-face

interviews. Considering the significant regional differences in Chinese society, respondents were selected using a multistage, cluster, stratified Probability Proportional-to-Size (PPS) sampling technique. CLDS has interviewed households in 29 provinces, the information involves demographic, economy, society, and other aspects, which provide objective social science data for economic research.

Moreover, we used the Digital Financial Inclusion Index (DFII) of China, which was compiled by the Peking University Institute of Digital Finance and Ant Financial Services Group based on the big data from Ant Financial Services to reflect the development of digital finance. The index comprehensively examines the development of digital finance from various aspects, including the coverage breadth, the usage depth, and the degree of digitalization. Among them, the coverage breadth of digital finance uses the number of bank cards bound in digital accounts as an indicator; the usage depth is composed of six categories of indicators such as payment business, monetary fund business, and credit business; The digitization level is constructed according to four categories of indicators such as mobilization. The index covers 337 cities above the prefecture level and more than 2800 counties in 31 provinces in China from 2011 to 2020. The data of control variables at city level were drawn from the China City Statistical Yearbook.

Since rotating samples were conducted in the survey, there were no tracking samples to meet the requirements. According to research needs, we used mixed cross-sectional data from 2016 and 2018. This paper selects relatively large-scale farmers, excludes the samples that are not engaged in agricultural production and have no agricultural income, and the samples which are missing the main variables. According to data released by the third General Census of Agriculture, the average business scale of rural households in China is 0.52 ha, and there are 90% of rural households operating arable land of less than 0.66ha in 230 million rural households. Consistent with China's national conditions, most of the farmers surveyed in CLDS are smallholders. Meanwhile, following the study of Qian et al. [58], farmers with planting sizes over 0.66 ha are defined as relatively large-scale farmers in this paper. After omitting cases missing essential data, the final dataset comprised 2776 samples.

3.2. Variables

3.2.1. The Dependent Variable

We use gross margin as a proxy for agricultural income, which is obtained by subtracting the total agricultural operation cost from the total agricultural income. Agricultural income includes income from vegetables, orchards, forests, grains, livestock, animal husbandry, and fisheries. The logarithmic transformation is performed to fit skewed data distributions into a normal distribution.

3.2.2. The Core Independent Variable

We used the digital finance general index to measure the development of digital finance. This index is the most representative indicator, it has been widely used by many scholars [59,60]. Since this study selected the dependent variable from the questionnaire of CLDS2016 and 2018, and considering that the CLDS2016 and 2018 questionnaire surveyed the sample in 2015 and 2017, we applied the total index of China's digital finance at the prefecture-level in 2015 and 2017 to match the questionnaire of CLDS2016 and 2018.

3.2.3. The Mediating Variables

Agricultural production factors mainly include agricultural capital, land, and workforce. Agricultural capital is determined based on the operating costs for seed, fertilizer, pesticides, fuel, and machinery expenses (not capital investments), as well as service items such as machine hire, paid and unpaid labor, marketing, storage, and transportation. The agricultural workforce is the number of people who engage in agricultural production for more than three months within one year. Agricultural land is the total area used to cultivate crops and animal husbandry.

3.2.4. The Control Variables

Drawing on the existing literature [28,61] we controlled the following variables: At the individual level, including the household decision maker's gender, age, education, health condition; at the family level, we control for family size, political status, family dependency ratio, the share of females, partially or fully mechanized farming methods, and the farm type of farmers. At the village level, we control whether this village has a non-agricultural industry, whether the village provide agricultural services (including unified planting, pest control, and skill training), whether there is a bank facility, the distance between the village and the county center. At the prefecture level, the ratio of the primary industry is selected because they are potential confounders of their relationship with the agricultural income.

The definitions and descriptive statistics of each variable are listed in Table 1.

Table 1. The definitions and descriptive statistics of each variable.

Variables	Definition	Mean	S.D
	Dependent Variable		
Gross margin	The natural logarithm of the difference between total agricultural income and total agricultural operation cost	9.2085	1.6973
	Core Independent Variable		
Digital finance	Digital financial inclusion index.	184.7302	27.2802
	Mediation Variable		
Agricultural capital	The natural logarithm of the total cost of agricultural operation.	8.8677	1.1907
Agricultural workforce	The number of people engaged in agricultural production for more than three months within one year.	2.0904	0.8633
Agricultural land	The natural logarithm of the land is used to cultivate crops and animal husbandry.	3.0871	0.7682
	Individual Level		
Gender	Men = 1, Women = 0.	0.9135	0.2811
Age	The family decision maker's age.	52.4373	10.1482
Education	No schooling = 1, Primary school = 2, Junior high school = 3, High school = 4, University degree or above = 5.	2.5771	0.8093
Health	The family decision maker's health status. Very unhealthy = 1, Moderately unhealthy = 2, General = 3, Healthy = 4, Very healthy = 5	3.5973	0.1000
	Family Level		
Size	The number of members.	4.9640	2.1066
Female	The percentage of women in the family.	48.7483	14.3049
Depend	The proportion of young people aged 0-14 and the elderly persons over 65 in the family.	23.7897	21.1900
Status	The number of Communist Party or democratic party members in the family.	0.2158	0.5260
Mode	1 if partially or fully mechanized farming, 0 otherwise.	0.7911	0.4066
Farm type	Crop farming = 1, Breeding industry = 0	0.9546	0.2082
	Village Level		
Non-agricultural industry	1 if there is a non-agricultural industry in this village, 0 otherwise.	0.1153	0.3194
Bank	1 if there is a bank facility, 0 otherwise.	0.9564	0.2042
Distance	The natural logarithm of the distance from the village to the county center.	2.1678	0.9121
Service	1 if the village provide agricultural services, 0 otherwise	0.7727	0.4192
	Prefecture Level		
Primary industry	The ratio of the primary industry to total GDP in each city.	13.6011	7.3486

3.3. Method

Firstly, the ordinary least-square estimation method is used to explore the impact of digital finance on relatively large-scale farmers' agricultural income and test Hypothesis 1. Our empirical model can be represented as follows:

$$income_{it} = \alpha_0 + \alpha_1 digital_{it} + \alpha_2 x_{it} + \lambda_t + \varepsilon_{it} \quad (1)$$

where $income_i$ denotes farmer i's agricultural income; $digital_i$ denotes the digital finance index of the city where farmer i located; x_i is control variables; λ_t denotes the time fixed effect, and ε_{it} is the random error term of the model.

In order to examine Hypothesis 2–4, we construct the multiple intermediary effect model. The models are set as follows:

$$med_{it} = b_0 + b_1 digital_{it} + b_2 x_{it} + \lambda_t + \varepsilon_{it} \quad (2)$$

$$income_{it} = c_0 + c_1 digital_{it} + c_2 med_{it} + c_3 x_{it} + \lambda_t + \varepsilon_{it} \quad (3)$$

where med_i stands for the farmer i's agricultural capital, agricultural workforce, and land. On condition that b_1 is significant, if c_1 and c_2 are both significant at the 10% level and the value of c_1 is lower than α_1, it indicates that the mediating variable has played the role of a partial mediator; if c_1 is insignificant, but c_2 is still significant, there is a complete mediating effect. Even though the coefficients b_1 and c_2 are significantly non-zero, it does not ensure that the mediating effect $b_1 c_2$ is significantly non-zero at the same time; for this reason, this paper uses the Sobel test statistic for its robustness test.

4. Empirical Results

4.1. Main Findings of Basic Regression

To ensure the stability and accuracy of the benchmark test, this study adopts the heteroscedasticity robust standard error to prevent the possible heteroscedasticity problem. Table 2 displays the estimated results, indicating the impact of digital finance on relatively large-scale farmers' agricultural income is positive at the 1% significance level. We claim that Hypothesis 1 is confirmed. Digital finance does improve agricultural income. Nevertheless, the coefficient is 0.023. In terms of economic significance, every one unit increase in digital finance index can lead to an average increase of about 2.31% in agricultural income.

Table 2. Estimated results of digital finance index on the agricultural income.

Variables	Gross Margin
Digital finance	0.0231 *** (0.0030)
Gender	0.0403(0.1245)
Age	−0.0088 *** (0.0034)
Education	0.0825 * (0.0452)
Health	0.1605 *** (0.0310)
Size	0.0019(0.0142)
Female	0.0014(0.0026)
Depend	−0.0070 *** (0.0014)
Status	0.1494 *** (0.0496)
Mode	0.2520 *** (0.0808)
Farm type	−0.3215 * (0.1637)
Non-agricultural industry	−0.0507 (0.1177)
Bank	0.0015 (0.1230)
Distance	−0.0696 (0.0495)
Service	−0.0923 (0.0913)
Primary industry	0.0199 *** (0.0066)
Time fixed effects	Yes
Constant	4.9886 *** (0.6624)
Observations	2776
R-squared	0.0675

Notes: * and *** respectively indicate significance at the level of 10% and 1%; Heteroscedasticity robust standard errors are shown in parentheses.

In addition to the core independent variables that have significant impact on relatively large-scale farmers' agricultural income, a total of seven control variables also have significant impact on agricultural income. Specifically, education level, health status, number of party members, mechanized farming, and the proportion of primary industry positively promotes agricultural income. It is worth noting that the positive effect of household decision-makers' education on agricultural income reflects the importance of farmers' human capital. Therefore, in the context of digital transformation, more relatively large-scale

farmers should be equipped with new agricultural knowledge and skills, while paying attention to the financial behavior characteristics of relatively large-scale farmers and improving their digital financial literacy. In contrast, age, dependency ratio, and farm type negatively impact agricultural income. The higher the dependency ratio and household decision maker's age, the less labor supply affects agricultural production. This result is in line with the former analysis. The non-agricultural industry in the village will cause the transfer of the agricultural workforce, thus substituting non-agricultural income for agricultural income.

4.2. Endogenous Problem and Robustness Test

4.2.1. Endogenous Problems

A critical problem in regression analysis is that the basic regression results may be endogenous: First, data entail a measurement error problem. Although the CLDS adopts proportional probability sampling (PPS) with stratification, multistage, multi-level, and population proportionality, there are inevitably data collection errors in the micro surveys. Second, theoretically, unobservable factors may affect agricultural income, resulting in estimation errors caused by missing variables. Third, the complex causal relationship between digital finance and agricultural income is still unclear for rural areas in different stages of digital finance development. A reverse causal relationship may exist: agricultural income may impact the use of digital finance, resulting in simultaneous bias. Therefore, this paper used instrumental variables to solve any other endogeneity problems that the above problems may cause.

In order to avoid any other possible endogeneity problems, this study selects "the average value of the digital financial index of other counties in the province where the farmer is located except this city" as the instrumental variable of the digital financial index of the city where the farmer is located. The selection of this instrumental variable is based on the following considerations: First, the development level of digital finance in this city is related to the development of digital finance in other cities in the province. Moreover, due to the low liquidity of relatively large-scale farmers, there is no direct relationship between the development of digital finance in other cities and relatively large-scale farmers' agricultural income, which meets the exogenous requirements of instrumental variables. Therefore, we carried out a two-stage least squares (2SLS) estimation using the internet as the instrumental variable for digital finance. Table 3 column (1) shows that in the first-stage regression, the instrumental variable has a significant impact on the independent variable, satisfying the correlation requirements for the instrumental variable. As shown in column (2) in Table 3, the value of the Cragg–Wald F statistic is 128.594, which is larger than the critical value at the 10% level of the Stock–Yogo weak identification test in parentheses, representing that the instrumental variable is not a weak instrumental variable. Therefore, this IV had good properties. The results of IV regression indicating the previous conclusions are robust.

Table 3. Estimated results of IV-2SLS.

	(1) **The First Stage**	**(2)** **The Second Stage**
	Digital Finance	**Agricultural Income**
IV	0.2002 *** (0.0189)	
Digital finance		0.0500 *** (0.0150)
Control variables	Yes	Yes
Year fixed effects	Yes	Yes
Cragg–Wald F statistic		128.594
10% max IV size		16.38
Observations	2766	2766

Notes: *** respectively indicate significance at the level of 1%; Heteroscedasticity robust standard errors are shown in parentheses.

4.2.2. Robustness Test

To further check the robustness of the model estimation results, three strategies were implemented: replacing core explanatory variables, removing extreme values, and adding control variables.

First, replace the explanatory variable. Drawing on the method proposed by Cao et al. [62], considering the cyclical nature of agricultural production, there may be a lag in the impact of digital finance on agricultural income. This study replaced the independent variable with one-period-lagged independent variable, namely the digital finance index for 2014 and 2016. As shown in column (1) in Table 4, the one-period-lagged digital finance index could significantly improve relatively large-scale farmers' agricultural income. The benchmark regression results still hold.

Table 4. Robustness tests by substituting independent variable and eliminating extreme values.

	Gross Margin	
	(1) Substitute Independent Variable	**(2) Eliminate Extreme Values**
One-period-lagged Digital finance	0.0249 *** (0.0031)	
		0.0229 *** (0.0030)
Control variables	Yes	Yes
Year fixed effects	Yes	Yes
Observations	2766	2766
R-squared	0.0704	0.0675

Notes: *** respectively indicate significance at the level of 1%; Heteroscedasticity robust standard errors are shown in parentheses.

Second, to reduce the influence of extreme values, we winsorized the agricultural income at the bottom and top 1% of their distributions. We eliminated one percent of samples at both ends for robustness check. The results are shown in column (2) in Table 4; the digital finance still has a positive effect on agricultural income, confirming the robustness of the benchmark results.

Third, from the agricultural land and agricultural workforce perspective, land registration and certification and whether the village organizes farmers to work are added to the regression. In Table 5 column 1, we added the variable of land registration and certification; the proxy variable is the question in CLDS: "Has your family received the Rural land Contractual Management Right Certificate?". Valued 1 if the respondent has answered Yes, 0 otherwise. In Table 5 column 2, we added the variable of whether the village organizes farmers to work, and the proxy variable of the latter one is the question: "Are there any agents organizing jobs for farmers?". Valued 1 if the answer is Yes, 0 otherwise. The regression results are shown in Table 5, and the previous conclusions are robust.

Table 5. Robustness tests by adding variables.

	Gross Margin	
	(1) Confirmation of Agricultural Land Rights	**(2) Organize Labor to Go Out to Work**
Digital finance	0.0251 *** (0.0032)	0.0219 *** (0.0031)
Control variables	Yes	Yes
Year fixed effects	Yes	Yes
Observations	2766	2766
R-squared	0.0833	0.0688

Notes: *** respectively indicate significance at the level of 1%; Heteroscedasticity robust standard errors are shown in parentheses.

4.3. Mediation Effect Analysis

The above theoretical part analyzes the mediation role of agricultural production factors between digital finance and agricultural income. Next, we intend to examine the three potential influencing channels of digital finance on agriculture income by the sequential test method. Since gross margin = total agricultural income-total agricultural operation cost, and agricultural capital are the operating costs. To avoid multicollinearity, we replace gross margin with agricultural income as the independent variable in this section. The results are shown in Tables 6 and 7.

Table 6. Digital finance and agricultural production factors.

	(1) Agricultural Income	(2) Agricultural Capital	(3) Agricultural Workforce	(4) Agricultural Land
Digital Finance	0.0157 ***	0.0177 ***	−0.0042 ***	0.0058 ***
	(0.0019)	(0.0020)	(0.0015)	(0.0012)
Control variables	Yes	Yes	Yes	Yes
Constant	7.2000 ***	6.7766 ***	2.2647 ***	1.7733 ***
	(0.4125)	(0.4233)	(0.3130)	(0.2717)
Year fixed effects	Yes	Yes	Yes	Yes
Observations	2776	2776	2766	2776
R-squared	0.1346	0.1399	0.0809	0.1006

Notes: *** respectively indicate significance at the level of 1%; Heteroscedasticity robust standard errors are shown in parentheses.

Table 7. Digital finance, agricultural production factors, and agricultural income.

	Agricultural Income		
	(1)	(2)	(3)
Digital Finance	0.0035 ***	0.0161 ***	0.0123 ***
	(0.0013)	(0.0018)	(0.0017)
Agricultural Capital	0.6900 ***		
	(0.0161)		
Agricultural Workforce		0.0940 ***	
		(0.0262)	
Agricultural Land			0.5966 ***
			(0.0287)
Control variables	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Constant	2.5243 ***	6.9872 ***	6.1420 ***
	(0.3306)	(0.4150)	(0.3923)
Sobel Z	8.771 ***	−2.266 **	4.368 ***
The ratio of mediation effect	77.48%	2.50%	22.10%
Observations	2776	2776	2776
R-squared	0.5721	0.1392	0.2770

Notes: ** and *** respectively indicate significance at the level of 5% and 1%; Heteroscedasticity robust standard errors are shown in parentheses.

Firstly, examine whether digital finance can influence agricultural income through agricultural capital investment. It is shown in column (1) of Table 6 that the coefficient of digital finance is positive and significant at the 1% level. The results in column (2) of Table 6 show that the coefficient of the impact of digital finance on agriculture capital is positive, indicating that digital finance has promoted relatively large-scale farmers' agriculture capital investment. The results in column (1) in Table 7 show that agriculture capital has a significantly positive impact on agriculture income. Meanwhile, after adding the variable of agricultural capital, the coefficient of the impact of digital finance on agricultural income is still significant, suggesting that agriculture capital has a certain mediating effect. Hypothesis 2 is verified. The results of the Sobel mediating effect test show that the effect of agriculture capital as a mediating variable is positive at the 1% significance level, and the mediating effect size is 77.48%, the largest one, which reveals the importance of agricultural capital in promoting agricultural income compared with other production factors.

Secondly, examine whether digital finance can influence agricultural income through the agricultural workforce. Digital finance has a significantly negative influence on the agricultural labor force (see column 3 in Table 6); at the same time, the agricultural labor force has a significant impact on agricultural income and the coefficient is positive (see column 2 in Table 7). In addition, after joining the intermediary variable agricultural workforce, digital finance still has a significant positive impact on agricultural income, which fits Hypothesis 3. However, the results of the Sobel mediating effect test show the mediating effect value of agricultural workforce accounting only for 2.50% of the total effect, which is the weakest in the mediating variables. It may be that with the non-agricultural transfer of labor, farmers may choose to purchase agricultural machinery [62] or outsourced agricultural mechanization services to cope with the labor shortage in agricultural production [63].

Thirdly, examine whether digital finance can influence agricultural income through agricultural land. As we can see from column (4) in Table 6 and column (3) in Table 7. Digital finance has a significantly positive influence on agricultural land, and after adding the intermediary variable agricultural land into regression, the coefficient of digital finance and agricultural land both are positive. It suggests that digital finance can indirectly facilitate agricultural income through promoting rent-in land. The Sobel test indicates that 22.10% of the effect of digital finance on agricultural income is through the promotion of agricultural land. Hypothesis 4 is verified.

Through the discussion of the above mechanisms, this paper finds that there are two positive mechanisms for expanding agricultural capital and agricultural land, and a negative mechanism for reducing agricultural labor in the channels that digital finance affects the agricultural income of relatively large-scale farmers. However, in general, digital finance still has a significant effect on agricultural income.

5. Heterogeneity

5.1. Heterogeneity Analysis Based on Agricultural Services

China has a vast territory; there are significant differences between regions in terms of natural and cultural environment and agricultural production and farming conditions. The agricultural services for farmers in different areas are not uniform, including agricultural materials supply, unified planting, pest control, and machinery. As the service improves the efficiency of agricultural technology, agricultural service has been unanimously welcomed by farmers in China [64]. Column 1 and 2 in Table 8 present that digital finance significantly positively impacts agricultural income for relatively large-scale farmers who receive both pest control and unified planting planning services. With agriculture services, it is more conducive for relatively large-scale farmers who access to digital finance to overcome the drawbacks of land fragmentation, control natural risks to a certain extent, reduce operating costs, and expand crop output. Digital finance could fully play the income-increasing effect.

Table 8. Estimated results of different categories according to whether receiving agricultural service or not.

	Gross Margin			
	(1) **Receiving Service**	**(2)** **No Service**	**(3)** **Receiving Skill Training**	**(4)** **No Skill Training**
Digital finance	0.0274 *** (0.0063)	0.0217 *** (0.0033)	0.0229 *** (0.0040)	0.0175 *** (0.0047)
Control variables	Yes	Yes	Yes	Yes
Constant	3.0818 *** (1.3707)	5.6774 *** (0.7395)	4.8823 *** (0.9096)	5.9753 *** (1.0387)
Year fixed effects	Yes	Yes	Yes	Yes
Observations	524	2252	1543	1233
R-squared	0.1546	0.0616	0.0749	0.0825

Notes: *** respectively indicate significance at the level of 1%; Heteroscedasticity robust standard errors are shown in parentheses.

5.2. Heterogeneity Analysis Based on Human Capital

The technical perception of farmers could be enhanced via training in the economic, scientific, and technical. For relatively large-scale farmers, agricultural production skills are their important human capital. The improvement of agricultural production skills can help improve agricultural productivity and the quality of agricultural products. Therefore, we divided the samples into two groups according to whether they obtained agricultural skills training or not. Columns 3 and 4 of Table 8 show that farmers who receive agricultural skills training can strengthen the positive impact of digital finance on agricultural income. Therefore, to give full play to the increasing effect of digital finance on agricultural income, attention should be paid to the training of agricultural production skills for relatively large-scale farmers.

5.3. Heterogeneity Analysis Based on Breeding Industry, Grain Crop, and Cash Crop

Finally, different agricultural production fields require different input factors; we divide agricultural production into the breeding industry, grain crop, and cash crop. From Table 9 we can see that digital finance has a significant positive impact on cash crops. However, the impact on grain crops is not significant. Moreover, digital finance has a negative but insignificant impact on the breeding industry. The breeding industry is increasingly tending to large-scale development with a high technical level and abundant capital. For farmers, it is harder to enter into the breeding industry than the crop industry. Currently, the scale of digital finance is smaller than traditional finance, and the economic benefits of digital finance for cash crops are stronger than for grain crops, so farmers as rational economic actors, pursue the maximization of their interests, who participating in digital finance are more inclined to invest their funds in the cash crop. Therefore, in the context of digital finance, the local government should optimize and adjust the planting structure on the premise of respecting the wishes of farmers and being guided by market demand to ensure food security and help farmers increase their income.

Table 9. Estimated results of different categories according to the types of agricultural production.

	Gross Margin		
	(1) **Breeding**	**(2)** **Grain Crop**	**(3)** **Cash Crop**
Digital finance	−0.0062 (0.0258)	0.0037 (0.0044)	0.0457 *** (0.0138)
Control variables	Yes	Yes	Yes
Constant	8.6918 *** (4.6717)	6.6769 *** (0.9121)	4.3803 *** (2.9828)
Year fixed effects	Yes	Yes	Yes
Observations	317	2773	647
R-squared	0.0657	0.1974	0.1645

Notes: *** respectively indicate significance at the level of 1%; Heteroscedasticity robust standard errors are shown in parentheses.

6. Conclusions and Discussions

Digital finance could change the allocation of agricultural production factors of relatively large-scale farmers with different endowments, thus affecting agricultural income. Based on the data from CLDS 2016 and 2018, this paper uses the multiple intermediary effect model to reveal how digital finance impacts agricultural income from the perspective of factor allocation. The present study's findings show that: (1) digital finance promotes relatively large-scale farmers' agricultural income significantly; (2) agricultural capital, agricultural land, and agricultural workforce play a partial mediating role between digital finance and relatively large-scale farmers' agricultural income. However, the mediating role of the agricultural workforce is the weakest, and the mediating role of agricultural capital is the strongest in the three mediation variables; that is, relatively large-scale farmers

participating in digital finance are more inclined to invest more in the agricultural field to gain more income. The sustainable financial transformation driven by digital technologies offers new opportunities for the agricultural sector. Digital finance can provide sufficient financial power for agricultural industrialization. Agricultural modernization and rural revitalization in China are designed to increase yields and incomes, with the transformation focusing on the means of production and technological development rather than on laborers. The development of intensive smart farming and the application of agricultural information technology will continue to displace the agricultural workforce. However, the demand for professional farmers will undoubtedly be more urgent. This result further confirms that the mediating role of agricultural land is more significant than the workforce. Promoting rent-in land for professional farmers is beneficial to gaining scale economy; and (3) considering the heterogeneity, further analysis finds that the development of digital finance has a more significant positive impact on the agricultural income for relatively large-scale farmers who receive agricultural skill training, agricultural service, and engage in the crop industry instead of the breeding industry. Even though this study only concerns the impact of digital finance on agricultural income in China, our findings can have important implications for countries urgently needing high-quality development.

This study has several policy implications. First, it underscores the need to develop digital finance. Digital finance provides an important scenario platform with which financial institutions could continuously innovate the modes and means to match and offer better support for agriculture. The policy maker should give full policy support to vigorously improve the digital infrastructure to address barriers attributed to the digital divide, especially in the rural area and those areas with poor natural endowments. Second, implement appropriate policy preference for new forms of financial services, expand the agricultural credits for the farming sector, and release new vitality for high-quality development of the agricultural economy. Third, actively cultivate a group of new business entities and family farms with modern business concepts, which is beneficial to rent-in agricultural land and realize moderate-scale agriculture. Fourth, farmer training programs typically result in human capital acquisition. The government should emphasize providing more targeted programs and specific training for farmers and be in charge of implementing measures for cultivating new professional farmers.

There are still some limitations in this paper. China's digital finance development is currently leading in the world. Whether the experience of the Chinese in supporting agricultural development with digital finance can be applied to other countries remains to be seen. Furthermore, we argue that the mechanisms of how mobile payment, online credit, online insurance, and online wealth management impact agricultural income are different. This could be an excellent opportunity for future research to investigate.

Author Contributions: Conceptualization, K.S.; methodology, Y.T. and K.S.; software, Y.T.; validation, K.S.; formal analysis, Y.T. and K.S.; investigation, D.Z.; resources, H.G.; data curation, Y.T.; writing—original draft preparation, K.S. and Y.T.; writing—review and editing, K.S., Y.T., D.Z., H.G. and W.K.; visualization, D.Z., H.G. and W.K.; supervision, K.S. and D.Z.; project administration, K.S.; funding acquisition, H.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Social Science Foundation of China (Grant No. 21XGL008).

Institutional Review Board Statement: Not applicable.

Data Availability Statement: All relevant data are within the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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The Impact of Government Agricultural Development Support on Agricultural Income, Production and Food Security of Beneficiary Small-Scale Farmers in South Africa

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Abstract: Enormous Literature indicates that agriculture remains a source of livelihood for about 86% of rural people and generates job opportunities for approximately 1.3 billion small-scale farmers and landless workers. Over the past couple of years, the South African government has been offering varied support to households that are engaged in small-scale farming to improve their livelihoods, income and food security. Although the various rounds of the General Households Survey (GHS) gathered information on the type of agricultural support received by the farmers about their food production, agricultural income and food security status, there is still limited pragmatic evidence on the extent to which programme is yielding the intended results. The main aim of the study was to use GHS data spanning the period 2013 to 2016 to assess how government agricultural development support influences the livelihoods of small-scale farmers in South Africa. Using both descriptive analyses with Propensity Score Matching (PSM) and Logistics estimations, the result of the study indicates that the proportion of households who have access to the agricultural development support have decreased marginally by two percent from 16% in 2013 to 14% in 2016. The study also reveals that agriculture development assistance given by the South African government is effective in reducing food insecurity, improving agricultural production and income of the beneficiary small-scale farmers. Following the observed marked gender, racial and geographical differences in households' access to the agricultural development support, the Ministry of Agriculture and its allied ministries and departments responsible for the implementation of the agricultural development support programmes must streamline policies to account for the lack of support to farmers in general. Addressing such differences is necessary to ensure that the programme achieves its intended overall objectives.

Keywords: agricultural development support; food security; livelihood; production; small-scale farmers

Citation: Mokgomo, M.N.; Chagwiza, C.; Tshilowa, P.F. The Impact of Government Agricultural Development Support on Agricultural Income, Production and Food Security of Beneficiary Small-Scale Farmers in South Africa. *Agriculture* **2022**, *12*, 1760. https://doi.org/10.3390/agriculture12111760

Academic Editors: Hung-Hao Chang, Pei-An Liao and Jiun-Hao Wang

Received: 12 September 2022
Accepted: 20 October 2022
Published: 25 October 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction

Agricultural development support has continued to be one of the key strategies of governments in developing countries for enhancing the livelihood of farmers, primarily small-scale farmers [1–3]. Enhanced food production, food security and higher rural income have been the primary targets of governments in developing countries [4–6].

The green revolution is a testimony to the effectiveness of agricultural development support, which contributed to a significant reduction in poverty, improved food security, agricultural income and transformation of the economy of many Asian and Latin American countries during the 1960s and 1970s [7–9]. Although this strategy was successful in these countries, it was the opposite in Africa due to environmental, political and economic differences [10–13].

At the regional level, the Southern African Development Community (SADC) members acknowledged that the agricultural sector remains central to poverty reduction, growth

and sustainable food security in the region [14]. This sector provided livelihoods such as food, income and employment for nearly 70% of the SADC population [14].South Africa is one of the SADC participating countries. The support for small-scale farmers in South Africa began in the 1980s by the Development Bank of Southern Africa (DBSA) with the critical purpose of addressing constraints of farmers in the homeland areas [15]. This effort, named Farmers Support Programme (FSP), was a tool that the government developed to assist small-scale farmers in the homeland areas to improve their agricultural production, food security and income through comprehensive agricultural support [16,17].

The FSP provided small-scale farmers with comprehensive agricultural support, including production inputs through credit, mechanisation services, agricultural infrastructure, extension and research services, training and marketing. According to [16,18,19] the FSP was successful because farmers who participated in this programme gained improved access to inputs, extension services and mechanisation along with increased production. However, little attention was given to market development and institutional capacity-building.

After 1994 (post apartheid era), agriculture was identified as one of the sectors to be developed through land reform programmes of which the main focus of support has been on small-scale farmers. Although the agricultural development support is implemented on the number of initiatives, the biggest expenditure is on land reform and the Comprehensive Agricultural Support Programme (CASP) of which the impact has been small, with few farmers benefiting [20].

Programmes implemented under land reform can be classified into three types, namely land tenure, redistribution and restitution. Land tenure involves "addressing the challenges associated with the administration of land in the communal areas of the former homelands", which has the highest concentrations of poverty in the country [21,22] Land restitution was meant to "redress historical injustices perpetrated through dispossession". land redistribution is aimed at "providing previously disadvantaged Black South Africans with land for settlement and small-scale farming purposes" [21,22].

Redistribution of land is generally considered to have the potential to improve the livelihoods of the rural poor significantly and to propel economic development [23]. The government established the farmers support programmes mainly meant for the land reform beneficiaries, but also none land reform beneficiaries, taking cognisance of the fact that not all small-scale farmers are beneficiaries. The support includes on- and off-farm infrastructure, training and capacity building, technical advice and assistance, marketing and business development, information and knowledge management, financing mechanisms, free inputs and vaccination and agricultural production loans.

The 2016 GHS showed that small-scale farmers received agricultural development support from the government, private sector, Community Based Organisations (CBOs) and Non-Governmental Organisations (NGOs) [24–27]. Assistance included training, extension services, grants loans in the form of money, loans in the form of input, free inputs, vaccination, and other unspecified forms of support. The link between these assistances and the livelihood of small-scale farmers is shown through improved income, productivity and food security.

Many of these small-scale farmers have received agricultural development supports but remain unproductive [28,29]. This situation raises a concern about the interventionist and one-dimensional approach used by the government over the years, which could engender continuous dependence of farmers on such supports. Although there seems to be a consensus that lack of monitoring and institutional coordination have engendered the ineffectiveness of the numerous agricultural development support policies and programmes, one possible challenge is the limited number of empirical studies that have assessed the effectiveness of these policies from a nationally representative perspective.

Lack of policy cohesion and coordination has led to duplication, uncoordinated efforts and inadequate progress towards national and international development targets of food security [29]. Although agricultural production is heterogeneous between small-scale

farmers, several studies have shown that farmer's characteristics such as age, level of education, farming experience, marital status, household's size and gender affect their farm productivity [30–32]. Contrary heterogeneity also exists on the different types of support because farmers receive additional support, which leads to different outcomes on productivity, income and food security.

Even so, earlier studies have shown that the agricultural output of small-scale farmers in the country is generally low due to several limitations that they face [33–36]. Amongst these limitations is reduced access to finance, lack of access to market, poor infrastructure, low level of education, lack of production inputs such as seeds and fertiliser, climate change, droughts, soil erosion, water pollution and other factors [37–43]. These constraints have impacted the effectiveness of various agricultural development support policies and programmes in achieving the intended objectives of reducing chronic hunger, unemployment, absolute poverty and inequality [39,40]. Therefore, sufficient and adequate agricultural development support must address these challenges and improve the livelihood of small-scale farmers through enhanced agricultural production, income and food security.

The study provided an alternative to the approach used by the Food and Agricultural Organisation (FAO). The FAO approach uses country's food balance sheet to estimate calories intake per person calorie distribution in the population and establish a calorie cut-off point that is used to estimate the number of undernourished people [44]. Another aspect of this study which makes it unique, is that it uses an innovative approach to link farmers who were assisted with those who were not supported, using the type of assistance that they received as an identifier. Although the study is not a pure RCT, this approach helps to make it possible to obtain reliable and valid estimates that may not differ significantly from those of pure RCT. Finally, the contribution of this study is that, unlike the previous studies that cover only some provinces or communities within provinces, this study uses a nationally representative household survey, and pooled data across four survey periods.

2. Materials and Methods

2.1. Data

The GHS is a nationally representative household survey conducted annually by Stats SA since 2002. It is a household-level survey instrument used to determine the progress of development in South Africa. It is used regularly to gauge the performance of programmes and the quality-of-service delivery in several key service sectors in the country [24–27].

This study relies on the secondary data from the last four rounds of the GHS, which were conducted in 2013, 2014, 2015 and 2016 by Statistics South Africa (StatsSA). The survey contains detailed information on agricultural development supports given by the government to small-scale farmers, food security status of households including those of the small-scale farmers, income from sales of farming products and services and production of livestock. The information makes GHS an ideal source of data for the analyses of this study and over the years. The GHS data has been used in several studies covering agricultural support, food security, poverty and health [33,45–47].

Drawing on the research design of the GHS, the research design of this study is both cross-sectional and quantitative in nature. It is quantitative in the sense that it follows an approach that involves the testing of objective theories by examining the relationship among variables. The variables are consequently measured, typically on instruments, so that numbered data can be analysed using statistical procedure [48,49]. The design is also cross-sectional because it involves the collection of data from the study population at a single point in time to examine the relationship among variables [48,49].

The GHS involves a multi-stage sampling design. The "first stage is based on a stratified design with probability proportional to size selection of Primary Sampling Units (PSUs) which is the Census Enumeration Area (EAs)".The "second stage involves the sampling of Dwelling Units (DUs) with systematic sampling". "After allocating the sample to the nine provinces, the sample was further stratified by geography (primary stratification) and by population attributes using census 2011 data (secondary stratification)" The "data

collection process also involved a visit by the enumerators to the sampled dwelling units in each of the nine sampled provinces" [24–27].

"The visit was meant to inform the sampled dwelling units about actual data collection, which took place four weeks later". As presented in Table 1, a pooled data of 19,620 sample size is expected to be used for the analyses. The study pooled the last four rounds of the GHS data for the analyses because over the years, the survey has gathered the same information but not from the same households and individuals. The observations of variables on agricultural development support for some of the surveys are to allow for parametric analysis. As a result, pooling the four rounds as a composite data improved the sample size.

Table 1. Surveyed and sampled households for agricultural development support.

Year	Total Household Sample	Sampled Households	Percentage Share in the Total Sample
2013	25,786	5901	22.89
2014	25,363	5819	22.94
2015	21,601	4209	19.49
2016	21,228	3691	17.39
Total	93,978	19,620	20.88

Source: The General Household Survey [2013, 2014, 2015 and 2016].

2.2. Estimation Techniques

Secondary data was used to address the objectives of the study. The initial stages of the analyses entailed an exploration of the data and the socio-economic variables that were included in the models. All the necessary data of the existing variables and generation of the indicators of food security, income and production were done at this stage of the analyses using the STATA version 14 software package. An assessment of this nature requires pure Randomised Control Trial (RCT). RCT is designed to test a hypothesis under optimal setting in the absence of confounding factors [50].

One of the approaches predominantly used in the literature in the modelling of quasi-experimental studies of this nature is the Propensity Score Matching (PSM) estimation method which also was applied in this analysis to quantify the impact of the government's agricultural development support on the livelihood of the small-scale farmers. The PSM identifies respondents who were assisted similar to those who were not assisted based on observable characteristics. The first step in computing the PSM involves the estimation of the predicted probability that small-scale farmer will be selected for assistance. From Equation (1) of the theoretical model, the equation for the logistic regression can be specified as: p(x_i) = Probability ($A_i = 1|x_i$).

The logistic regression is used to estimate the propensity score [p(x_i)], by regressing the agricultural development assistance (1 = assisted and 0 = not assisted) on the observed observable covariates. The next step of the estimations process involves in the choice of a matching estimator, which can be done using several matching algorithms. However, this study applies three algorithms (i.e., nearest neighbour matching, kernel matching, and the radius matching technique) to ensure that the estimates are robust, the statistical significance of the average treatment effects on the quantities treated was tested using bootstrapped standard errors, which takes into account the variation that is caused by the matching process. The mathematical framework for the different algorithm for the PSM estimations and other relevant equations have been discussed extensively in [51–54].

The choice of the covariates was informed by two main conditions, as discussed in the literature. First, only variables that influence the treatment status (a receipt of agricultural development support) and the outcome variables (production, food security and income from agricultural activities) simultaneously. Second, the variable should be included, given that confoundedness requires the outcome variable(s) to be independent of treatment

conditional on the propensity score [55,56]. Only variables that are unaffected by treatment should be included in the model. On the other hand, a variable should only be excluded from analysis if there is a consensus that the variable is either unrelated to the outcome or not a proper covariate. Complications can be minimised by using relevant variables were included in the propensity score estimations as recommended by [57].

Despite its qualities of producing robust estimates, one of the downsides of the PSM that needs to be highlighted is the likelihood of hidden bias. Hidden bias may occur when there are unobserved variables that affect both the variable of interest (receiving assistance) and the outcome variables see [54]. For instance, the PSM estimates can be over-estimated in conditions where households that were assisted were also likely to improve their productivity, income and food security. The hidden bias was addressed by including important observable individual and household level characteristics in the estimation of the propensity score specification to minimise any tendencies for omitted variable bias. Also, the matching process was implemented around the region of standard support see [53]. Thirdly, different matching algorithms were estimated to ensure the consistency of the results.

Food insecurity as another dependent variable was computed as a score from ten questions on food security in the GHS. More questions on this variable are clearly defined on Section 3.2 (Measurement of variables and a priori expectation).

2.3. Theoritical Model

The theoretical model that supports the empirical analysis of this study is adapted from the theory of net farm exits as espoused by [58–60]. The model proposes that when deciding on either quitting or continuing to engage in farming, farmers weigh the utility derived from continuing to farm with the utility that they would derive from quitting and becoming unemployed in the farming industry. This decision can be presented by matching the present value of expected future utility that a farmer would derive from farming at time t as Vtf, with that of quitting as Vtq. The farmer will quit if Vtf < Vtq but he/she continues to farm if Vtf > Vtq.

The farmer's utility depends on his/her consumption levels, which in turn are dependent on his/her income or returns to labour (and capital) invested per unit of time invested in agriculture or off-farm work. Maximisation of utility is subject to three constraints: (1) budget constraint considering farm income (including direct payments), off-farm wage and non-labour income; (2) time allocation constraint that allows the farmer to spend all available labour on-farm, off-farm and leisure time; (3) existing farm production technology.

The farmer maximises a utility function (U), which is a function of goods consumed (C), leisure time (L), non-pecuniary benefits of being self-employed (S), and exogenous shifters (α). This can be functionally specified as:

$$U = u(C,\ L,\ S;\ \alpha) \tag{1}$$

This maximisation of this utility is subject to income constraint (Equation (1)) and time constraint (Equation (2)).

$$P\gamma(K,\ R;\ \beta) + G - \varnothing K + \varphi V - f(T) + A = C\ P\gamma D = L + R + V \tag{2}$$

From Equations (1) and (2) P denotes farm output price; γ is the farm production function; K is the quantity of variable non-labour inputs; R is the number of days worked on-farm; β is a vector representing other fixed characteristics of the farmer.

Similarly, G denotes total farm government programme payments, such as direct payments; $\varnothing$ is the vector of prices of the variable representing non-labour inputs; φ represents the daily wages from off-farm market work, and V is the number of days invested in off-farm employment. Finally, $f(T)$ is total transaction costs of working off the farm; and A denotes unearned (non-labour) household income; while D is the total time (hours, days, or weeks) available.

Assuming the objective of the rational small-scale farmer is to maximise his/her household income (Equation (1)), optimal labour allocation requires that the Marginal Value Product (MVP) of the labour used on-farm must be equal to the expected level of (off-farm) market wage. If the farmer decides to shift all available time from on-farm activities to off-farm activities, R will be equal to zero ($R = 0$). The value of on-farm labour MVP (i.e., the increase of revenues coming from an additional day worked on-farm) can be specified as Equation (3).

$$MVP = p = MPP \tag{3}$$

From Equation (3), $MPP = \partial Q/\partial df$ represents the marginal physical productivity of farm labour. Agricultural development policies can affect labour allocation decisions in two main ways: the first is by decreasing the level of risk associated with farming; the second is by directly supporting farm income. However, this study focuses on the second effect of agricultural development because direct payments affect labour allocation decisions in a more indirect way than price policies. The effect of direct payment changes according to the nature of payments as direct payments can be coupled to the production level, to the amount of land or heads of livestock, or can be separated from production.

Assuming the total amount of direct payment that a farmer receives (G) may be affected, directly or indirectly, by the number of days worked on-farm (df) and by other farm-specific characteristics (γ), such as current and past production patterns and farm location, this yields a generic and very simplified Equation (4):

$$G = g(df; \gamma) \tag{4}$$

Suppose direct payments are coupled to production (Coupled Direct Payment (CDP)), farmers are motivated to produce and to use more resources, including labour. A surge in the use of labour on-farm may contribute to an increase in the total amount of direct payments received by the farmer.

$$\frac{\partial G}{\partial df} > 0 \tag{5}$$

Equation (5) depicts that agricultural development support (CDPs) received by farmers has the potential to induce an upward shift of their marginal value product and, consequently, their income and food security.

2.4. Theoritical Framework

Market Failure underpins the empirical analysis of this study because the objectives of the study fit well into the central tenet of this theory. The theory postulates that, under certain conditions commodity production and distribution in a competitive market characterised by pursuing of own self-interest of relevant agents, will result in the allocation of a socially inefficient commodity [61]. [62] describes market failure as a signal of the inability of a market economy to reach specific desirable outcomes in resource allocation. These expositions suggest that whenever a market failure occurs, the government's intervention in regulating the market to achieve a more optimal distribution of resources is necessary.

Ref. [63] explained that the term "market failure" does not necessarily mean that a market is not working at all, but that it is not working because it is not producing goods that are wanted. Market failure may occur due to either supply or demand-side factors. It is a pervasive phenomenon in agriculture, especially in developing countries [64]. Ref. [65] discoursed that market failure is the product of the cost of the transaction through a market exchange which creates a disutility that is greater than the utility gain that it produces and mostly results in the market not being used for the transaction.

As a significant feature of the agriculture industry market failure manifests itself in many forms including but not limited to, unpredictable prices, unstable supply, low and volatile income for farmers, environmental costs of intensive farming (negative externalities), agriculture as an essential component of the life of rural residents (positive externalities), and monopsony power of food purchasers [66]. Price volatility of agricultural

commodities is driven by a combination of factors, such as: (1) supply is price inelastic in the short term because production is time demanding; (2) demand is price inelastic because food is a necessity, and higher prices do not usually deter people; (3) climatic conditions can alter the supply of agricultural products.

Any of these factors resulting in market failure can affect the prices of agricultural products and the revenue of farmers in one way or the other [67]. A sharp reduction in price due to any of the mentioned factors may cause a fall in farmers' revenue. A glut in supply equally may throw farmers out of business because prices can fall significantly below cost. Similarly, the cobweb theory predicts that prices can become stuck in a cycle of continually increasing volatility. The cyclical volatility of prices could occur if prices in a particular year fall below certain levels, forcing many farmers out of business [67].

Drawing on welfare economics theories, agricultural economists have proposed several theories to explain how the government can intervene to address the market imperfections often associated with the agricultural economic system. Such interventions include direct income support, implementation of regional labour market policies, and the abolition of price support policies [68]. The government can build buffer stocks to support price stabilisation, and institute price floors and price ceilings to regulate supply and stabilise farmers' income.

The government can also set minimum prices (price floors) to guarantee farmers' basic income by subsidising food prices. However, minimum prices may encourage oversupply and lead to excess production that may go waste. Another tool at the disposal of government to cushion the income and enhance the production of farmers is subsidies for farmers who adhere to more environmentally friendly methods of production. Import tariffs have also proved to be a useful policy tool to protect domestic farmers, although they cause the domestic price of agricultural produce to increase, leading to lower trade.

In the context of developed countries, one school of thought, led by [69], posited that two main factors largely influence agricultural support policies. The first factor is the country's position as either a net exporter or net importer of agricultural products. Net importing countries of agricultural products usually provide higher support to farmers than their counterparts net exporting countries. The second factor is the farmer and non-farmer income differences. This school of thought assumes that the maximisation of a social welfare function based on egalitarian value preferences, which are relatively stable, reflects the behaviour of the political system. Like economic models, the model of this school of thought has been criticised because in general, as well as specific contexts, the model is unable to address several questions related to the characteristics of agriculture [68].

To propose a model to support the Common Agricultural Policy (CAP) introduced by the European Union, Nedergaard combined the traditional welfare economic theory of agriculture with the rational choice theory [68]. The model considers individual decision-makers in the market (producers and consumers) as the unit of analysis at the microeconomic level. Within the political-economic system, the microeconomic model of supply and demand considers the political decision-makers such as politicians and bureaucrats, political partners who constitute producers and consumers as the decision-units.

The principal assumption of the model is that politicians and bureaucrats are the ones who supply political decisions, while producers and consumers demand political decisions. Like the neo-classical microeconomics theory, maximisation of the utility function, regardless of the unit of analysis, remains the principal objective of all parties. At the micro-level, market failure takes place when economic actors resort to potential rent-seeking behaviour in the political system, a situation which translates into government failures, and consequently affects the microeconomic level [68,70]. The model depicts a structural causality between factors within the economic and political systems. It is assumed that several economic interests in the political system that try to build coalitions due to differences in political decisions translate into different cost and benefits for the various groups in society [68].

The model postulates that market failure in the agricultural markets, due to the intense political voice of farmers, could attract political intervention, a situation which will be eventually decided by the equilibrium between the supply of political decisions by politicians and bureaucrats on the one hand, and the demands of the farmer-producers, consumers and taxpayers on the other hand [68]. The importance of the redistribution of resources through government intervention is a common theme that runs through both the welfare economic theory and its later applied version in the agricultural industry. Therefore, government intervention to address any possible market failures that could contribute to sub-optimal and inefficient production.

Ref. [71] argued that government intervention is necessary to address public concerns regarding the inequality in the distribution of income, which is a sign of market failure. Government intervention in agriculture is aimed at the development of the sector. For instance, many countries developed their agricultural sector using various forms of direct or indirect government subsidies [72,73].

According to [73], most governments in developed nations subsidise farmers, while developing nations tax farmers with the ultimate rationale of stabilising prices, supporting the use of fertiliser, building irrigation systems, offering extension services, and providing credit rates that are often below the market rates. These supports often have counter-productive impacts by imposing enormous financial burdens on the government and generating allocative inefficiencies in low-income countries. The definition of market failure has been based on the two theories, which included the public goods and externalities explained below.

Based on the principles of market failure, it can be deduced that the economic agents who are mostly affected by this phenomenon are the small-scale farmers who often have face high cost of the transaction to be able to access markets [64]. Transaction costs have a significant influence on small-scale farmers' resource allocation decisions. [74] argued that high transaction costs deter small-scale farmers from entering the market, and this deprives them of the benefits associated with commercialisation in agriculture. As mentioned in the previous paragraphs, other factors from the small-scale farmers' perspective that could lead to market failures include changes in climatic conditions and price volatility.

These require the government's interventions to reduce such transaction costs to encourage more farmers to participate in competitive markets. Therefore, a subsequent increase in productivity and thus help in meeting the South African government's broader objectives of ensuring poverty alleviation in the country. While government intervention is considered necessary to correct the market failure in agricultural production, it comes with its problems. Studies suggest that the cost of subsidising agriculture, especially in developed countries, is high.

It is estimated that the cost of supporting agricultural producers in advanced countries in the year 2000 was about $245 billion, which was five times the total development assistance received by developing countries [67]. It has also been found that farmers who own large amounts of land and have virtually no incentive to follow more environmentally friendly procedures are the ones who often receive subsidies. Minimum prices have been found to contribute to over-supply, while tariffs on agriculture often lead to lower income for food exporters in the developing countries and these have been barriers to trade [75,76].

3. Results and Discussions

3.1. Descriptive Analysis

The rationale behind the South African government's agricultural support policies and programmes is to make the sector more robust by increasing equity amongst the farmers with regards to gender, race, modern technology and other agricultural support [77]. Figure 1 depicts a considerable reduction in the percentage of farmers who received the assistance of 16% and 14% in 2013 and 2016, respectively.

In addition to the observed disparities in production across gender, marked differences can be observed in Figure 2 that farmers who received the assistance had higher production

of all types of livestock than their counterparts who had not received the assistance. This observation is consistent across the gender of the respondent. However, the production gap among males is higher than the gap among females. While it is evident from these results that the agricultural support programme has the potential to be effective in helping the small-scale farmers to increase their productivity and some fundamental factors such as gender, and geographical differences need to be given critical attention for the programme to yield its intended results.

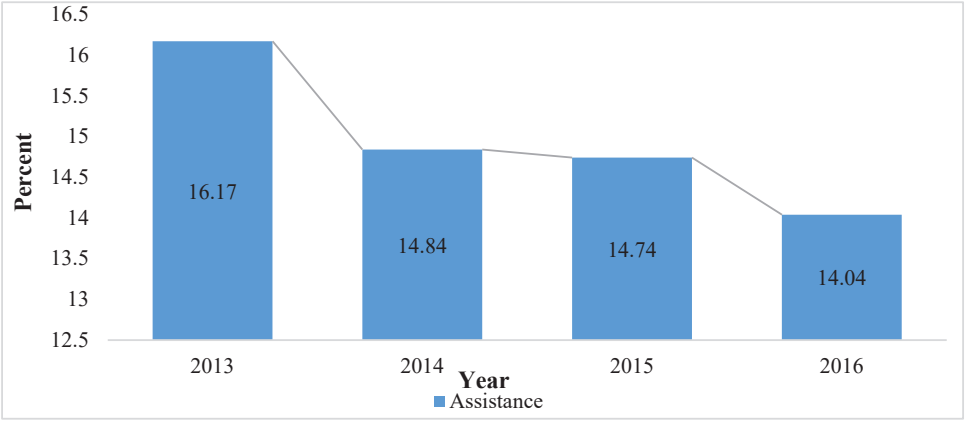

Figure 1. Number of farmers who received assistance from 2013 to 2016.

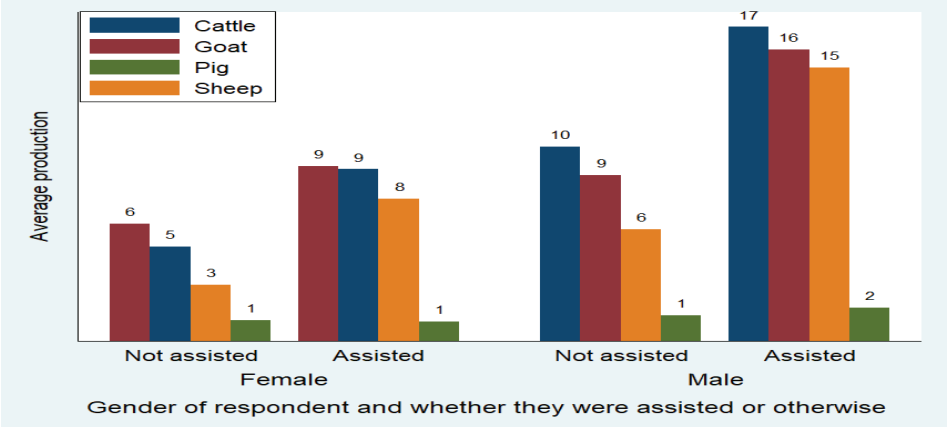

Figure 2. The difference in the production rate between those who received assistance and those who did not receive.

Across respondent gender, it is depicted in Figure 3, that production is generally lower among females than males. Unlike pig production, there is a significant difference in the number of cattle, sheep and goats produced by males compared to females. The implication that can be drawn from these results is that the implementers of the policy would have to consider gender as an essential factor in the implementation of the policy to ensure that women are given the needed assistance that will enhance their ability to optimise agricultural development support.

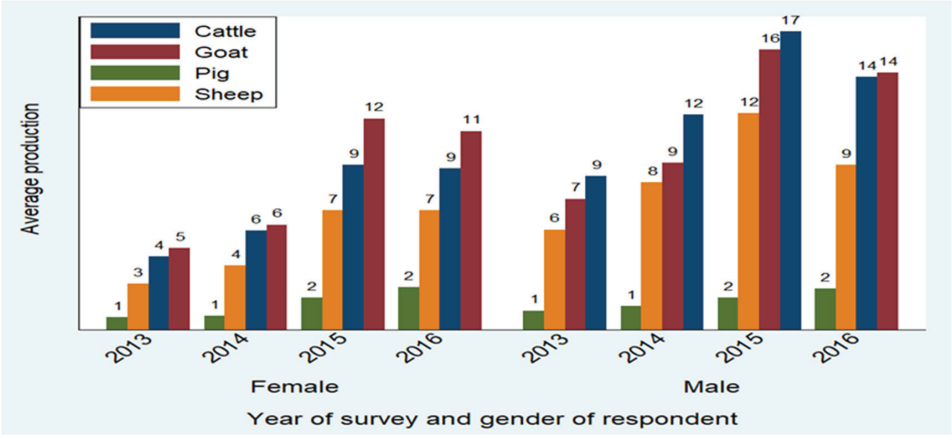

Figure 3. Average livestock production by gender and assistance status of the respondent.

As expected, the gender inequality in earnings from agricultural activities is depicted in Figure 4, and this is consistent across all the survey periods. The gap has been widening to the extent that, since 2015, the average income of males who were assisted was more than twice that of their female counterparts. Considering the respondents who never received any support, the gap is relatively lower compared to those who were assisted. These trends support the assertions made in the preceding paragraphs that there is the need for gender mainstreaming in the implementation of the programme to ensure that it does not worsen the already existing inequalities among the small-scale farmers.

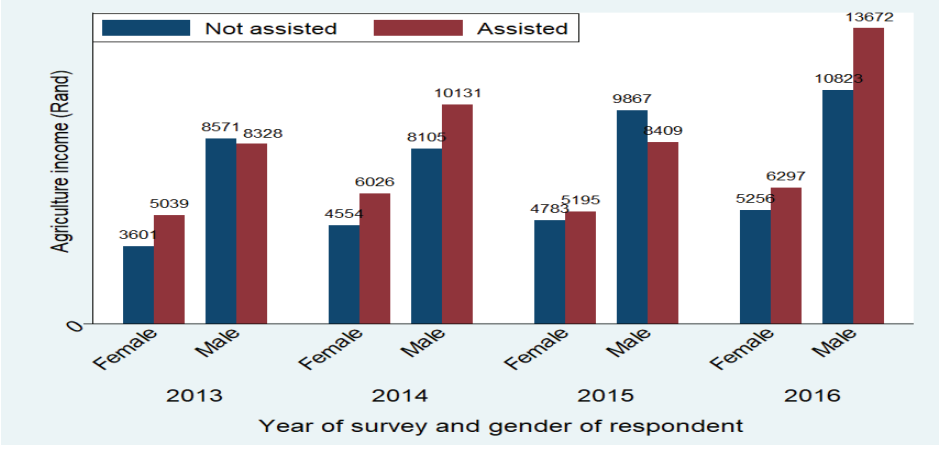

Figure 4. Average agriculture income by gender and assistance status of the respondent.

Across the geographical location of the respondent, the results in Figure 5 shows that the impact of the support does not have the same effect on the income of the beneficiary farmers. For instance, [78] had investigated the impact of microfinance on agricultural productivity by small-scale farmers in Tanzania, Iramba district; the results have shown that credit beneficiaries realised high agricultural productivity compared to non-credit beneficiaries. In some of the provinces, farmers who never received any assistance had higher agriculture income than those who were assisted. For instance, in the Eastern Cape, Mpumalanga and Limpopo, male farmers who were not supported had an average

income higher than their counterparts who were supported. Similarly, female farmers in the Western Cape, Northern Cape, North-west and Gauteng provinces who were not supported had higher average agriculture income than those who received the support. On the bases of these results, the province-specific factors that affect the full realisation of the impact of the programme among all the beneficiary farmers must be considered while implementing and evaluating the effectiveness of the programme. Apart from climatic conditions, institutional bottlenecks, corruption in the form of diversion of the resources intended to support the farmers, and other individual challenges faced by the farmers due to their geographical location, need to be assessed and addressed.

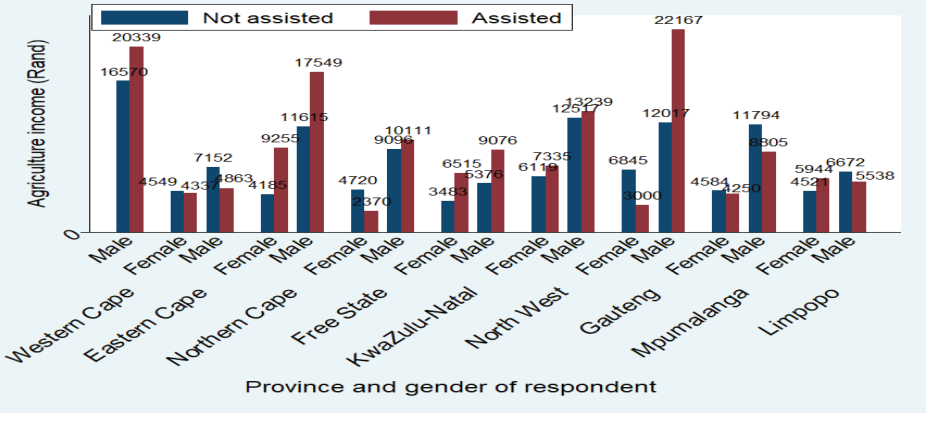

Figure 5. Average agriculture income by gender and province of respondent.

Consistent with the distribution of production and agriculture income across the year of survey and support status of respondents, the results in Figure 6 indicate that food insecurity has reduced within the four years. However, the sudden increase in food insecurity in a 2016 survey period mainly, among females raises concern for more policy effort. The figure shows that food insecurity is relatively higher among females than males, possibly due to the observed low income and productivity among females. Another observation that needs extra policy effort is that the food insecurity gap between respondent who were assisted and those who were not assisted has narrowed. This indicates the growing ineffectiveness of the programme in achieving its intended purpose.

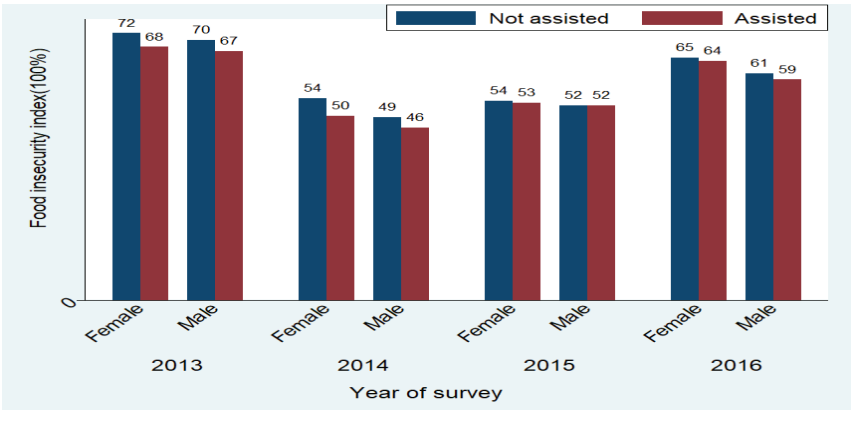

Figure 6. Food insecurity by gender and assistance status of the respondent.

The results across the geographical location of respondents in Figure 7 depict some heterogeneities observed in the previous paragraphs. In the Western Cape Province, information available for food insecurity was for only those who never received the assistance. In the Eastern Cape and Northern Cape provinces, food insecurity is unusually higher among both males and females who received the support than those who never received any support. In the Gauteng province, food insecurity is higher among females who received the support than those who did not receive the support. Two factors can explain these and similar observations across production and income. First, respondents had already high level of food insecurity. The second possible reason includes unequal production capacity, unequal access to the support and regional variation in the climatic conditions.

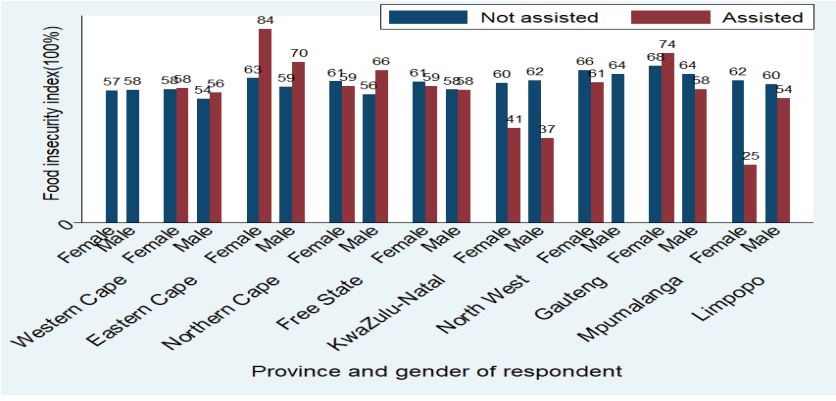

Figure 7. Food insecurity by province and assistance status of the respondent.

3.2. Measurement of Variables and a Priori Expectations

Considering the objectives of the study, one of the policy variables of interest in the analysis is agricultural development assistance. During the survey, the respondents were asked if their household had received any agricultural-related assistance from the government during the previous 12 months such as training, extension services, grant (loans), agricultural inputs for production, dipping and vaccination services for livestock and any other assistance to improve their productivity. From this list of variables, agricultural development assistance was computed as a binary to take on the value one if the household responded that it received at least one form of assistance, and zero if nothing materialised.

Food insecurity as another dependent variable was computed as a score from ten questions on food security in the GHS. The household was asked if: In the past 12 months, any adult had suffered from hunger, any child experienced hunger or starvation, Minors which end up in streets, and if money shortage were experienced, reduction in meal portions, food reduction for several days.

Questions 1–3 had six possible responses (Never; Seldom; Sometimes; Often; Always; and Not applicable) while questions 4–10 were binary (Yes or No). Questions 1–3 were recorded as binary to take on the value one if the household's response was either Seldom, Sometimes, Often, or Always, and 0 if they Never responded or Not applicable. Questions 4–7 were also recorded to take on the value one if the response was Yes, and 0 otherwise. These seven binary variables were used to compute a score of food security. Following [79], this study computed the food security score by summing the positive responses and divided the results by the total number of variables. The final score was multiplied by 100% to enhance the interpretation of the estimates.

The food security index ranged from 0 (Highly Food Secure) to 100 (Highly Food Insecure). The Cronbach's alpha value was used to test the reliability and consistency of the seven items on a single scale, measuring the score of food insecurity. The rule of thumb requires that a value of 0.80 and above should be considered as a good measure. Different

Cronbach's alpha values were computed for the index of the pooled sample. The estimated Cronbach's alpha value for the 2013 survey was 0.908 with an average interim covariate of 0.077, while the values for the 2014 survey was 0.900 and the covariate 0.0745. 2015′s alpha value was 0.903 and the covariate 0.076, while 2016′s was 0.903 with a covariate of 0.075. The alpha value for the pooled sample of the four rounds of the survey was 0.904, with an average interim covariate of 0.076.

In addition to these two variables, agricultural income, which is a continuous variable, was computed as the income that households receive from agricultural activities, such as the sale of agricultural products in the past twelve months. This study intended to investigate the household production of both livestock and food. However, the survey did not collect information on food production. The analysis is restricted to only livestock. Information on four main types of livestock (cattle, sheep, goats, and pigs) was available, which was used to compute the average livestock produced by households. Initially, the observations for these four types of livestock were captured as categories of intervals (0, 1–10, 11–100, 100 and above). Following [80], the mid-point value for each category was allocated as the actual production per household.

The dependent variables were also modified from how they were initially captured in the survey. For instance, land size ranged from less than 500 m^2 to 20 ha or more. However, the categories had few observations, and the variable land size was categorised into three categories (1 = less than 500 m^2; 2 = 500–999 m^2; and 3 = 1 ha and above). Responses such as Do not Know and Not Applicable were recorded as missing. Similarly, land ownership was recorded as binary, taking on the value one if the land used for the agricultural activity belonged to the farmer, and 0 otherwise. The observation that takes on the value 0 comprises rented land, sharecropping, tribunal authority, state land, and others. Responses such as Do not Know were recorded as missing.

The variable population group, household head, was categorical, with four options: 1 African/Black; 2 Coloured; 3 Indian/Asian; and 4 White. Education measures the level (categories such an ABET and Grade 12) of education that the respondent indicated that he or she completed. In the GHS, the responses ranged from Grade R/0 to a higher degree (Master's or Doctorate). The responses were categorised into one no education; 2 necessary education/primary; 3 secondary's; and four higher. Basic education included grades 1 to 9; Secondary covered Grade 10/Standard 8/Form 3 to Diploma with Grade 12/Standard 10; and Higher education comprised those who completed at least a Higher Diploma at a Technikon/University. Age was measured in the GHS as a continuous variable which ranged from 2 to 107 years. However, this study focused on respondents who were engaged in agricultural activities. Marital status was also captured in the GHS as one being legally married; 2 having lived together like husband and wife; 3 being divorced; 4 having separated, but still legally married; 5 being widowed; 6 being single but had been living together; 7 being single and had never been married, and eight unspecified responses. During the analysis, married respondents were classified, and cohabiting were categorised as an informal relationship. Those who were divorced, widowed, had separated, were classified as being single. Also, respondents who were single and had never been married were categorised as single.

Although the context and scope of this study may differ from previous studies, it is a priori expected that the age of the respondent, being male, and being Black/African should have positive effects on one's access to the programme. On the contrary, the higher level of education, large land size for farming, being the landlord, and being White, Coloured, or Indian/Asian should have a negative correlation with the probability of being assisted. The reason for these expectations is that there is a strong positive correlation between land size, level of education, and race on the one hand, and income level and living standards that warrant assistance on the other. The association between households' geographical location and the probability of the respondent receiving assistance remains indeterminate, since the characteristics of the province, and those of the beneficiaries of support, play an essential role.

3.3. Determinants of Farmers' Access to Agricultural Development Support

The results in Table 2 show that age is a significant determinant of a farmer's probability of being considered for support. The significance of age as a determinant of selection into the programme could also mean the experience in farming, which is a factor that implementers of the programme consider. The results also indicate that education is negatively associated with the probability of being selected for the agriculture development support. The effect of education is significantly higher for respondents who have higher levels of education. This is quite contrary to expectation because one would argue that those educated can put the assistance into better use for optimum outcome. However, from the perspective of the principles of distributive justice, the observed negative effect of education is intuitively acceptable in the sense that those who have low levels of education are more likely to be poor and need extra support to earn a living.

Table 2. Determinants of farmers' access to agricultural development support.

Agricultural Development Support	GHS2013	GHS2014	GHS2015	GHS2016	Pooled Sample
Age	0.001 ***	0.001 ***	0.002 ***	0.002 ***	0.001 ***
Male	0.024 ***	0.033 ***	0.023 ***	0.050 ***	0.030 ***
Primary	0.001	0.007	0.005	−0.003	0.003
Secondary education	−0.011	−0.004	−0.008	−0.005	−0.007 **
Higher education	−0.053 ***	−0.055 ***	0.024	−0.036 *	−0.035 ***
African	0.079 ***	0.051 **	0.061 ***	0.048 **	0.066 ***
Coloured	−0.058 **	−0.069 **	−0.029	−0.042 *	−0.042 ***
Land > 5 ha	0.081 ***	0.041 ***	0.104 ***	0.008	0.061 ***
>1 ha	0.190 ***	0.090 ***	0.178 ***	0.192 ***	0.162 ***
Landlord	−0.015 **	0.012 **	−0.004	−0.028 ***	−0.004
EC	0.186 ***	0.319 ***	0.144 ***	0.172 ***	0.209 ***
NC	0.074	−0.007	−0.112 ***	−0.134 **	−0.034 *
FS	−0.087 **	−0.003	−0.123 ***	−0.055	−0.073 ***
KZN	0.180 ***	0.236 ***	0.007	0.073 **	0.131 ***
NW	−0.105 **	0.017	−0.112 **	−0.073 **	−0.072 ***
GP	−0.073 *	0.013	−0.126 ***	−0.033	−0.057 ***
MP	−0.024	0.098 ***	−0.025	0.036	0.015
L	−0.120 ***	0.008	−0.126 ***	−0.059 *	−0.079 ***
Observations	19,143	196	1402	11,097	64,001

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Apart from education and age, the population group of respondents is significantly associated with the probability of receiving agricultural development assistance. An African or specifically, a black South African is more likely to be assisted compared to a farmer who is either a White, an Indian, Asian or a Coloured. From a gender perspective, the results show that a male is more likely to receive support than a female. This observation highlights the need for the government to consider gender mainstreaming and racial diversities in the implementation of the policy in order not to deepen the existing inequality in resource ownership and productivity in the country.

Land size used by farmers is an indication of their access to and use of the resource. In this analysis, land size for agricultural activities appears to be a significant determinant of farmers' access to agricultural development support. A farmer who owns a land size of at least 500 m square is significantly likely to receive support compared to his/her counterpart, whose land for farming is less than 500 m square. The coefficients are significantly higher for farmers whose land sizes are at least one hector and above. Implementation of the policy is built on the egalitarian principle; it also maintains an element of efficiency and economy of scale. Regarding the effect of land lordship on access to the support, the results reveal that compared to farmers who do not own their lands for farming, landlords are less likely to be assisted. The observed adverse effect of land ownership is that it qualifies as a surrogate for wealth or income level, which is a criterion for selecting the farmers who

should or should not benefit from the programme. It can be deduced that those who own lands have the potential to produce without much assistance.

Farmer's geographical locations are significant in determining their access to the programme. Consistent with the descriptive analysis, a farmer in either Eastern Cape or Kwazulu-Natal Province is more likely to be assisted compared to his/her counterpart in the Western Cape province. On the contrary, a farmer in the Northern Cape, Free State, and North-West, Gauteng, Mpumalanga or Limpopo province is less likely to receive the assistance. An earlier study conducted by [78] suggests that the incidence of both income and multidimensional poverty are higher in the Eastern Cape, Limpopo and Kwazulu-Natal provinces. The simultaneous dominance of these three provinces in the distribution of poverty and agricultural households largely justifies the regression results. It is intuitively expected that provinces that have high poverty rates and more agricultural households would be the focus of every policymaker who aims to reduce inequality.

The results highlight the need for policymakers to pay attention to the difference in the socio-economic factors such as race/population group, geographical location, level of education and household income status which influence farmers' access to the programme. Those factors have unstated implication for the extent to which the programme will be sufficient. Failure of policymakers to consider these factors in the implementation of the agriculture support programme could worsen the already high inequality in resource ownership, livelihood and welfare that permeates all facets of societies in South Africa. The next subsection discusses the effect of the programme on the livelihood of the beneficiary households, with a focus on their income, productivity and food security.

3.4. Impact of the Agricultural Assistance on Production, Income and Food Security

Having discussed the socio-economic factors that determine households' access to agricultural development assistance, this study goes further to assess its impact on households' food security, production and income from agricultural activities. However, before discussing the impacts (Average Treatment Effects), it is essential to discuss the balancing of the propensity scores from the logistic regression, as this shows the extent to which the differences across the two groups of small-scale farmers are reduced to identify a valid counterfactual efficiently. Figure 8 depicts the histograms of the predicted propensity scores for the two groups of small-scale farmers. From this figure, those farmers who received the assistance have equivalent matches from those in the comparison group. The graph suggests that there is overlap and similarity between the propensity scores of the two groups of small-scale farmers.

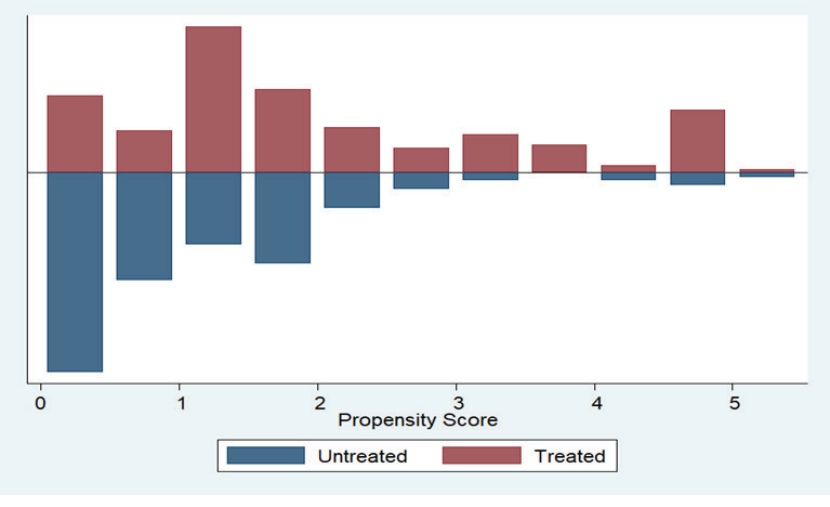

Figure 8. Propensity score distribution.

The estimates of the three propensity matching approaches (see Table 3) indicate that holding other factors constant, a household that receives the agriculture development support is about 1–1.5% less food insecure than a household that does not benefit from the programme. The household that receives the support is about 1–1.5% more food secure than a household that does not receive any support. The indicator of assistance is made up of different variables related to agricultural activities.

Table 3. Average Treatment Effects (ATE) of agricultural development support.

Dependent Variable	Nearest Neighbour Matching	Kennel Matching	Radius Matching
Food insecurity (index:0–100)	−1.485 ***	−1.532 ***	−1.099 ***
	(0.602)	(0.760)	(0.447)
Agricultural income (Rand)	59,002.380 ***	59,671.78 ***	51,989.66 **
	(21,174.18)	(21,802.84)	(22,548.75)
Cattle production	2.763 ***	2.323 ***	2.819 ***
	(0.392)	(0.510)	(0.315)
Goat production	1.293 ***	1.216 **	1.754 ***
	(0.372)	(0.568)	(0.315)
Sheep production	4.1998 ***	3.932 ***	5.021 ***
	(0.415)	(0.647)	(0.303)
Pig production	0.0998	0.0067	0.150 *
	(0.106)	(0.179)	(0.083)

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Source: Author's computation based on the GHS data.

These results verify the argument of [81] that the root causes of chronic food insecurity should be the priority objectives for development and that policymakers whose countries have been facing chronic food insecurity should aim to improve productivity and boost demand for the products and labour of food-insecure households. There is a need for reallocation of budgets toward rural populations whose livelihoods depend mainly on their agricultural activities.

Like the results on food security, the estimates of the effect of access to the agricultural development support on the agricultural income of farmers appear significantly positive. This means that a household that receives at least one form of support earns income ranging from R52,000.00 and approximately R60,000 than a household that does not receive any assistance. The results on both food security and agricultural income suggest that agricultural support programme is indeed beneficial to the small-scale farmers. According to [64], access to credit is believed to have a significant impact on the household livelihoods indicators such as agricultural productivity, food security and technology adoption.

The estimates of production of livestock confirm the observed results on food security and income of the beneficiaries of the programme. Holding other factors constant, a small-scale farmer who receives at least one of form assistance can produce 2 to 3 more cattle than his/her counterpart, who receives no assistance. Similarly, a farmer who receives any form of support from the programme can produce at least one more goat than a farmer who receives no support. It is evident from the results that, at the conventional levels of significance, the programme has a positive impact on the production of all the livestock except the pig. This case is supported by [82] who had analysed the demand allocation of credit and capital supports by farm household and impact on production, consumption and investment in the Nusa Tenggara Timur (ENT) province. The results have, however, revealed that allocation of credit and capital support increased cattle production, consumption expenditure and the investment of the household.

4. Conclusions

From 2013 to 2016 survey years, the proportion of households who have access to the agricultural development support has decreased marginally by about two percent. Therefore, this could be partly due to a reduction in the sample sizes of the GHS within

this period. It could also be attributed to human and institutional factors that are affecting the effective implementation of the programme to cover the target population. Consistently across the survey years, there are marked differences in access to the support across, gender level of education, race and geographical location of respondents. Access to support has remained high among males than females, farmers with the low level of education than those with high levels of education and also Black/Africans than other race (Coloured/Indians/Asians and Whites).

The regression analysis indicates that a wide range of socio-economic factors underlies the farmers' access to the agricultural development support programme. Prominent among these factors, which are significant in the models, are the gender, race, age and province of residence of the respondent. Other factors are the size and ownership status of the land used for farming. The Propensity Score Matching (PSM) analysis shows a significant positive impact of the agricultural development support on livestock production, income and food security of households than that benefit from the programme than those who receive no support. Based on these findings, the government must pay attention to the implementation process of the programme, taking into consideration the gender, racial and geographical diversities which may influence households' access to the support and the extent of effectiveness of the support on their livelihoods. Many times, households face several challenges in their quest to access the support of this nature. Such challenges include unfair distribution that favours only the friends and relatives of the implementers of the programme, corruption which leads to misallocation of the supports and misappropriation of funds earmarked for the implementation of the programme. [83] investigated the problems of supporting smallholder farmers in South Africa, and the findings revealed that the budgetary allocation to the sector had increased impressively over the last decade and the distribution of such resources are such that few farmers benefits but the impact is minimal. On the side of the beneficiaries of the programme, there is a need for effective monitoring and evaluation to ensure that support given to the households is put into efficient and effective use for their benefits and the benefit of the entire country. More importantly, the Ministry of Agriculture and its allied bodies must establish a mechanism to track all inappropriate actions of both the institutions/bodies responsible for the implementation of the programme and the beneficiary households or small-scale farmers. If such practices go unchecked, the government's rationale for rolling out the programme would not be realised.

Following the observed marked gender, racial and geographical differences in households' access to the agricultural development support, the Ministry of Agriculture and its allied ministries and departments responsible for the implementation of the agricultural development support programmes must streamline policies to account for the lack of support to farmers in general. Addressing such differences is necessary to ensure that the programme achieves its intended overall objectives.

As a common issue in research, this study has some limitations that need to be mentioned to guide future research and policies on this topic. One of the shortfalls of this study is that it relied on observational data instead of pure RCT data. Nonetheless, this limitation does not have much bearing on the estimates since the PSM, and its bootstrapping procedure, offers enough control measures to reduce any potential bias due to the use of the observational data. Future researchers could consider using observational data that follows the beneficiaries of the programme over time to gain more insight into other confounding factors that may affect the estimated impact of agricultural development support. This study was unable to address the transition from small-scale into commercial farming due to lack of information from the survey. Future studies purposely designed to assess the impact of the programme should critically consider this issue to enable policymakers to address it effectively.

Author Contributions: Conceptualization, M.N.M.; Methodology, M.N.M.; Software, M.N.M.; Validation, M.N.M.; Formal analysis, M.N.M.; Investigation, M.N.M.; Resources, M.N.M.; Data Curation, M.N.M.; Writing—Original Draft Preparation, M.N.M.; Writing—Review & Editing, M.N.M., C.C. and P.F.T.; Visualization, M.N.M.; Supervision, C.C. and P.F.T.; Project Administration, M.N.M., C.C. and P.F.T.; Funding Acquisition, M.N.M. All authors have read and agreed to the published version of the manuscript.

Funding: This study is funded and supported by the University of South Africa. We acknowledge the financial support from the University.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We want to acknowledge and thank the anonymous reviewers for their valuable comments and suggestions.

Conflicts of Interest: The authors declare no conflict of interest.

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Research on Environmental Governance, Local Government Competition, and Agricultural Carbon Emissions under the Goal of Carbon Peak

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Abstract: By introducing network game theory, this paper analyzes the internal relationship and interaction mechanism among environmental governance, local government competition, and agricultural carbon peak level. On the basis of theoretical analysis, a spatial panel model is constructed using panel data from 30 provincial-level regions in China for empirical analysis. The research finds that local governments have positive competition with respect to the agricultural carbon peak, they adopt complementary carbon peak competition strategies, and they are more inclined to take geographical distance to adjacent regions as the yardstick in the competition with respect to the agricultural carbon peak strategy. That is, when the carbon peak level of surrounding provinces increases, the carbon peak level of the region will also increase. Thus, there is a phenomenon of mutual imitation and convergence between neighboring provinces. Environmental governance has a significant positive direct effect and a positive spatial spillover effect. From the perspective of coefficient, its direct effect is significantly greater than the spatial spillover effect. Therefore, more attention should be paid to local environmental governance to promote the improvement of the agricultural carbon peak level. Furthermore, the agricultural industrial structure, fiscal decentralization, agricultural public investment, regional industrial structure, and the proportion of the rural population have significant spatial spillover effects. The agricultural industrial structure and fiscal decentralization are significantly positively correlated with the peak level of agricultural carbon while the proportion of the rural population is significantly negatively correlated with the peak level of agricultural carbon. The research results have important theoretical value for expanding the research in the field of agricultural carbon emissions and provide important practical reference for China to successfully achieve the goal of agricultural carbon peak and promote the high-quality development of agriculture

Keywords: local government competition; environmental governance; agricultural carbon peak; network game model; spatial Dubin panel model

Citation: Yang, Y.; Tian, Y.; Peng, X.; Yin, M.; Wang, W.; Yang, H. Research on Environmental Governance, Local Government Competition, and Agricultural Carbon Emissions under the Goal of Carbon Peak. *Agriculture* **2022**, *12*, 1703. https://doi.org/10.3390/agriculture12101703

Academic Editors: Hung-Hao Chang, Pei-An Liao and Jiun-Hao Wang

Received: 18 August 2022
Accepted: 12 October 2022
Published: 15 October 2022

1. Introduction

In recent years, the climate change caused by greenhouse gas emissions has caused a series of impacts on the natural ecosystem and human living environment [1], which has gradually attracted extensive attention from all over the world [2]. After China acceded to the United Nations Framework Convention on climate change with the approval of the National People's Congress in November 1992, following the initial passive response, China submitted to the United Nations General Assembly in 2015 its independent emission reduction commitment to reduce its carbon emission intensity by 60–65% by 2030 compared with that in 2005. By 2020, China proposed the initiative to put forward carbon peak and carbon neutral targets at the United Nations, so as to actively fulfill its emission reduction

obligations as a developing country. China's carbon emission intensity has continued to decline since the 12th Five-Year Plan period. Compared with 2005, it decreased by nearly 50% in 2020. Good progress has been made in reducing carbon emissions. However, according to the report of the International Energy Agency, China's carbon emission intensity in 2021 is still at a high level compared with developed countries, and there is still room for further effort in the implementation of the "double carbon" goal.

As a typical public resource, environmental protection cannot be separated from the government's constraints and control [3]. The government has an unshirkable obligation to deal with environmental problems including carbon emissions. China's carbon emission intensity has been attached great importance by the central government, as well as governments at all levels, since its incorporation into the national economic and social development plan as a binding indicator during the 12th Five Year Plan. The traditional performance assessment mechanism is gradually changing, and the assessment of energy consumption, carbon emissions, and other indicators is gradually being strengthened. Since 2021, China has established the strategic direction of ecological civilization construction by focusing on carbon reduction, with the establishment of a special leading group for carbon peak and carbon neutralization. In the future, all national policy tools and organizational arrangements will focus on carbon reduction and emission reduction. At the same time, local governments have also responded to the efforts of the central government. Provinces (municipalities directly under the central government and autonomous regions) have successively set up carbon peak and carbon-neutral leading groups. In addition, some local governments have also added carbon emission intensity indicators to relevant assessment indicators. For example, Shandong Province includes carbon emission intensity indicators in the comprehensive performance assessment of high-quality development of various cities while Jing'an District of Shanghai has formulated work assessment measures related to the 2022 "double carbon" target. The competitive behavior of local governments will have an important impact on the intensity of carbon emissions [4]. Scholars have gradually paid increasing attention to the impact of the competitive behavior of local governments with respect to carbon emissions.

The relevant theories on local government competition can be traced back to Adam Smith's period. Since then, many scholars have conducted corresponding research on the competitive behavior between governments from the perspective of public goods such as taxation based on the public choice theory [3,5–10]. Since the reform of the tax-sharing system in 1994, China has gradually formed a unique Chinese-style power-sharing system that combines political centralization and economic decentralization. Under this system, local governments directly or indirectly control a large amount of economic resources and play an increasingly important role in regional economic development and social governance. This institutional arrangement gives local governments greater rights to occupy and control economic resources, in addition to bearing most of the expenditure responsibilities. The responsibility for environmental governance falls more on local governments [11]. In 2020, the State Council issued a reform plan on the division of central and local fiscal authority and expenditure responsibility in the field of ecological environment, which specifies the control of greenhouse gas emissions and other matters within local administrative areas, recognizing them as the local fiscal authority, with the local government bearing the expenditure responsibility.

As the main body of environmental governance, local governments have more common strategic interaction in the formulation and implementation of environmental policies [12–17]. According to the existing research, there are two kinds of competition incentive mechanisms for environmental governance among local governments: bottom-up [18] and top-down [19]. Specific to the reality of China, strategic interaction between local governments mainly comes from political incentives, with performance evaluation playing a pivotal role. Performance assessment including environmental protection indicators has a positive impact on the promotion incentive of local officials [20]. Under the Chinese-style decentralization, performance assessment directly affects the implementation effect of envi-

ronmental policies [21]. Some scholars believe that local governments relax environmental regulation standards for the sake of economic benefits and other considerations, which will lead to a decline in local environmental quality, whereas competition among governments will increase local pollution emissions [22–24], aggravate environmental pollution [25], and lead to the phenomenon of a "race to the bottom". Zhang Z. has found through research that the competition situation of environmental governance among local governments is changing to strategic imitation, and this competition strategy is closely related to the change in official performance assessment indicators [26]. Strict environmental performance indicators will encourage local governments to imitate each other [27], having a certain enhancement effect on the "competitive upward" strategic behavior among cities [28].

Because of its own characteristics, agriculture is not only a huge carbon sink system but also one of the main emission sources of greenhouse gases [29,30]. The greenhouse gases emitted from agricultural production activities are mainly methane and nitrous oxide. The emissions of these two gases from agricultural production activities account for a high proportion of the total emissions. According to the content of the second National Information Circular of the People's Republic of China on climate change, in 2005, methane emissions from agricultural production activities accounted for 56.62% of China's total emissions, and nitrous oxide emissions accounted for 73.79% of China's total emissions [31]. The heat absorption efficiency of these two gases is higher than that of carbon dioxide, and their influence on promoting global temperature rise is more obvious. In addition to paying attention to the carbon emissions of the secondary and tertiary industries, the issue of agricultural carbon emissions is also an important issue that China must solve to achieve the "double carbon" goal. In the government work report of the Central People's Government of the People's Republic of China in 2022, it is emphasized to further promote the reduction in and efficiency of chemical fertilizers and pesticides, as well as the resource utilization of livestock and poultry breeding wastes, to develop low-carbon agriculture, and to promote agricultural carbon reduction and emission reduction [32]. There are many existing studies on agricultural carbon emissions and their reduction. The relevant studies mainly focused on the construction of agricultural carbon emission index systems [33,34], the calculation of agricultural carbon emissions [35–37], the efficiency of agricultural carbon emissions [38–40], and the influencing factors of agricultural carbon emissions [41–43]. According to the relevant literature, it can be found that the existing research on the competitive behavior of local governments in environmental aspects focused on environmental pollution control and environmental regulation while the research on environmental governance and carbon emissions also focused on carbon emissions in the industrial field. The existing research on the competitive behavior of local governments in agricultural carbon emission reduction is relatively scarce, with little direct elaboration on the specific mechanism of local government competition in the pursuit of the agricultural carbon peak.

This paper mainly studies the driving mechanism of the local government to achieve the agricultural carbon peak goal, the impact of environmental governance on the agricultural carbon peak level, and the impact mechanism of local government competition. Through the introduction of network game theory, this paper analyzes the strategic interaction mechanism of environmental governance, local government competition, and agricultural carbon peak goal. On the basis of theoretical analysis, the panel data of 30 provincial-level regions in the Chinese Mainland (excluding Hong Kong, Macao, and Taiwan) are used to construct a spatial panel model for empirical analysis. The research results can provide a reference for effectively promoting the implementation of carbon reduction and emission reduction in China's agricultural sector, successfully achieving the carbon peak goal, and ultimately mitigating global warming.

2. Environmental Governance, Local Government Competition, and Agricultural Carbon Peak: A Network Game Model

As the decision maker, the local government's behavior is affected by the behavior of neighboring local governments in the game process. On the basis of the research of Peng X. et al. [44], this paper introduces the network game model to analyze the competitive behavior of local governments in achieving the goal of agricultural carbon peak.

Suppose there are N local governments in a certain geographical area, $N = \{1, \cdots, n\}$, $n \geq 2$. If N local governments are abstracted into N nodes in the social network, a social network g in the geographical space can be formed. In this network, there are a series of interconnected relationships among N local governments, which can be expressed by the adjacency matrix $\boldsymbol{G} = [g_{ij}]$. If i is adjacent to j, then $g_{ij} = 1$; otherwise, $g_{ij} = 0$. Further, the network is an undirected network, i.e., $g_{ij} = g_{ji}$. In general, it is assumed that $g_{ii} = 0$, i.e., the local government i is not adjacent to itself, as reflected on the adjacency matrix, whereby the diagonal elements of $\boldsymbol{G}$ are all 0. In this network, the number of neighbors of local government i is expressed by d_i, which is the degree of the network node i.

This paper assumes that the agricultural carbon peak level of each local government is a continuous decision variable c_i. When $c_i \geq 0$, the spatial relationship network formed between local governments is represented by $\boldsymbol{G}$. Then, the benefit function of each local government to achieve the agricultural carbon peak goal can be expressed as

$$u_i(c, g) = [\sigma\alpha_i + \zeta_i(\mathrm{X})]c_i - \frac{1}{2}c_i^2 + \psi \sum_{j=1}^{n} g_{ij}c_ic_j, \tag{1}$$

where $\sigma > 0$, and $\psi > 0$. ψ reflects the strategic interaction of local governments in the agricultural carbon peak target action. Combined with the actual content of this study, it is assumed that local governments have strategic complementary behavior in the agricultural carbon peak target action. α_i is the unobservable heterogeneity of local governments, and $\zeta_i(X)$ is the heterogeneity of the captured exogenous decision. For the sake of simplifying the model, this paper only introduces the heterogeneity-influencing factor of environmental governance, which is an exogenous decision; thus, the specific expression of $\zeta_i(X)$ can be written as

$$\zeta_i(\mathrm{X}) = \beta_0 Env_i + \frac{1}{d_i(g)}\gamma_0 \sum_j^n g_{ij}Env_j, \tag{2}$$

where Env_j is the environmental governance variable that determines the observable influence factor of the heterogeneity of the agricultural carbon peak target income of each local government, β_0 and β_1 are relevant parameters, and d_i is the degree of the node of local government i, i.e., the number of neighbors in the network with direct neighbor relations.

This paper uses Katz–Bonacich centrality to examine the importance of nodes, by defining

$$\boldsymbol{M} = (\boldsymbol{E} - \psi\boldsymbol{G})^{-1} = \sum_{k=0}^{+\infty} \psi^k \boldsymbol{G}^k. \tag{3}$$

Then, the Katz–Bonacich centrality of individual i is defined as follows:

$$b_i(g, \psi) = \sum_{j=1}^{n} g_{ij} = \sum_{j=1}^{n} \sum_{k=0}^{+\infty} \psi^k g_{ij}^{[k]}. \tag{4}$$

For simplicity, it can be expressed in matrix form as follows:

$$\boldsymbol{b}(g, \psi) = \boldsymbol{M}\mathbf{1} = (\boldsymbol{E} - \psi\boldsymbol{G})^{-1}\mathbf{1}, \tag{5}$$

where $\mathbf{1}$ is the n-dimensional unit vector, and $\boldsymbol{E}$ is the unit matrix. Similarly, the centrality of the weighted Katz–Bonacich network can be obtained as follows:

$$b_\alpha(g, \psi) = \boldsymbol{M}\alpha = (\boldsymbol{E} - \psi\boldsymbol{G})^{-1}\alpha. \tag{6}$$

In Katz–Bonacich network centrality, matrix $\boldsymbol{M}$ is expressed as

$$\boldsymbol{M} = (\boldsymbol{E} - \psi \boldsymbol{G})^{-1} = \boldsymbol{E} + \psi \boldsymbol{G} + \psi^2 \boldsymbol{G}^2 + \ldots \tag{7}$$

$\boldsymbol{M}$ can be regarded as a social multiplier, which is the key mechanism to generate network effects. It can reflect the cascade characteristics and attenuation characteristics of different individuals in the network. In social networks, the behavior choices of individuals are influenced by neighbors, enabling their determination. Therefore, this mutual influence mechanism is persistent in the network until it reaches convergence under certain conditions.

In the game, local governments simultaneously choose their own agricultural carbon peak level to maximize their respective income functions. The optimal response function can be obtained from the first-order optimization conditions.

$$c_i{}^*(\boldsymbol{Env}, \boldsymbol{g}) = \sigma \alpha_i + \zeta_i(\boldsymbol{Env}) + \psi \sum_{j=1}^{n} g_{ij} c_j \tag{8}$$

Substituting Equation (2) into Equation (8) yields

$$c_i{}^*(\boldsymbol{Env}, \boldsymbol{g}) = \sigma \alpha_i + \psi \textstyle\sum_{j=1}^{n} g_{ij} c_j + \beta_0 Env_i + \dfrac{1}{d_i(\boldsymbol{g})} \gamma_0 \textstyle\sum_{j}^{n} g_{ij} Env_j, \tag{9}$$

which can be written in matrix form as $\boldsymbol{c}^* = [\sigma \alpha + \boldsymbol{\zeta}] + \psi \boldsymbol{G} y$. The carbon peak level of the game equilibrium can be obtained by solving the following equation:

$$\boldsymbol{c}^* = [\boldsymbol{E} - \psi \boldsymbol{G}]^{-1} [\sigma \alpha + \boldsymbol{\zeta}] = \boldsymbol{M} [\sigma \alpha + \boldsymbol{\zeta}], \tag{10}$$

where $\omega(\boldsymbol{g})$ is the maximum eigenvalue of the network adjacency matrix $\boldsymbol{G} = \left[g_{ij}\right]$. Then, the following proposition can be obtained: if $\psi \omega(\boldsymbol{g}) < 1$, there is a unique Nash equilibrium, and the equilibrium result is equal to the centrality of the corresponding weighted Katz–Bonacich network, i.e.,

$$c_i{}^*(\boldsymbol{Env}, \boldsymbol{g}) = b_{(\sigma \alpha + \zeta) i}(\boldsymbol{g}, \psi). \tag{11}$$

For the proof of this proposition, please refer to the appendix at the end of Helsley et al. [45]. The expression of the equilibrium agricultural carbon peak level of local government i can be specifically expanded as follows:

$$c_i{}^*(\boldsymbol{Env}, \boldsymbol{g}) = \sum_{j=1}^{n} \sum_{k=0}^{+\infty} \psi^k g_{ij}{}^{[k]} \left[\sigma \alpha_j + \zeta_j(\boldsymbol{Env})\right]. \tag{12}$$

It can be seen that the peak level of agricultural carbon in the Nash equilibrium depends on the network adjacency matrix and regional heterogeneity factors. The above formula also shows that, if a local government occupies a more dominant position in the network, i.e., if it has a greater Katz–Bonacich network centrality, it will also tend to choose a higher agricultural carbon peak level. In addition, when the impact of regional heterogeneity factors on environmental governance is positive, the peak level of balanced agricultural carbon will also increase. Obviously, ψ reflects the degree of strategic interaction between local governments, in addition to depicting the degree of strategic complementarity and competitive interaction in the network. An increase in ψ will significantly increase the agricultural carbon peak level of all local governments.

According to the theoretical model, ψ is internally consistent with the spatial dependence of local government competition, as discussed later in this paper. The spatial econometric model incorporates the action mechanism of the spatial autoregressive coefficient or spatial dependence parameter and the network game ψ. The spatial weight matrix is equivalent to the adjacency matrix in the network game model, which provides an important basis for this paper to organically combine the network game model of local

government competition with the spatial measurement model. In the demonstration of the spatial econometric model, this paper builds the corresponding estimation equation as a function of the expression of the optimal response function of the local government's agricultural carbon peak goal before conducting the corresponding empirical test.

3. Spatial Measurement Model Settings, Data Source, and Variable Description

3.1. Model Settings

On the basis of the theoretical analysis results of the network game model, this paper uses the spatial econometric model to test the impact mechanism of environmental governance and local government competition on the peak level of agricultural carbon. The network relationship weight $\boldsymbol{G}$ in the network game model has a certain commonness with the $\boldsymbol{W}$ in the spatial econometric model, and the social multiplier and the spatial multiplier have high similarity and internal correlation. According to the optimal response function of the local government, the spatial panel model set in this paper is

$$carbon_{it} = \rho \sum_{j=1}^{N} w_{ij} carbon_{jt} + \beta_0 Env_{it} + \gamma_0 \sum_{j=1}^{N} w_{ij} Env_{jt} + \sum_{h=1}^{H} \beta_h x_{it}^h + \sum_{h=1}^{H'} \sum_{j=1}^{N} \gamma_h w_{ij} x_{jt}^h + \mu_i + \varepsilon_{it}, \quad (13)$$

where i and j represent different provinces, t represents each year, $carbon_{it}$ represents the peak level of agricultural carbon in period t of the ith province, $carbon_{jt}$ represents the peak level of agricultural carbon corresponding to the competing provinces, x_{it} is the control variable that affects the peak level of agricultural carbon, Env_{it} represents the environmental governance of the ith province in period t, Env_{jt} represents the environmental governance corresponding to the competitive provinces, μ_i is the interprovincial individual effect, ε_{it} is a random disturbance term, and w_{ij} is the key spatial weight in the model. In the subsequent analysis, the spatial adjacency matrix is used as the basic regression, and the distance weight matrix, the distance square weight matrix, and the economic distance weight matrix are used for robustness analysis. As expressed in Equation (13), spatial autoregressive coefficients ρ, β_0, and γ_0 are the core parameters of this study. If ρ is significantly greater than 0, it indicates that local government competition has strategic complementary behavior; if ρ is significantly less than 0, it indicates that there is strategic substitution behavior in local government competition.

3.2. Data Source and Variable Description

Considering the availability and accuracy of the research content and data, this paper selects the data of various provinces and regions in China from 2005 to 2020. Due to the lack of data in Tibet, it was excluded, and a total of 480 research samples from 30 provincial-level regions were obtained. Relevant research data were obtained from the China fiscal Yearbook [46], EPS data platform [47], China Energy Statistical Yearbook [48], China Rural Statistical Yearbook [49], and China fiscal Yearbook [50].

3.2.1. Description of the Dependent Variable

The explained variable in the measurement model was the agricultural carbon peak level, which is expressed by subtracting the ratio of the agricultural carbon emission intensity value of each province and the agricultural carbon emission intensity value under the carbon peak state from 1. When the carbon reaches the peak, it means that at a certain time point, carbon dioxide emissions will no longer increase to the peak, and then gradually fall back. According to this background, this paper uses 35% of the national agricultural carbon emission intensity value in 2005 as the agricultural carbon emission intensity value in the carbon peak state. The agricultural carbon emission intensity used in this paper is the ratio of agricultural carbon emissions to the added value of the primary industry. The added value of the primary industry is adjusted by using the added value index of the primary industry in the base period of 2005. See the research of Tian Y. et al. [51] for the specific measurement method of agricultural carbon emissions. According to the definition, a greater peak level of agricultural carbon indicates greater achievements in agricultural

carbon emission reduction. When the peak level of agricultural carbon is less than zero, the intensity of agricultural carbon emission in this region has not reached the peak state; when the peak level of agricultural carbon is equal to zero, the intensity of agricultural carbon emission in the region has reached the peak state of carbon; when the peak level of agricultural carbon is greater than zero, the agricultural carbon emission intensity in this region has not only reached the expected peak state of carbon but is also further striving to achieve the goal of carbon neutralization.

3.2.2. Description of Independent Variables

The core explanatory variable used in the model was environmental governance (envpro). The calculation of environmental governance variables referred to the research of Chen S. et al. [52], whereby the government work reports of 30 provincial-level areas in the Chinese Mainland were manually collected from 2005 to 2020, before conducting word segmentation processing and statistical analysis. The frequency of words related to the environment in the provincial-level government work reports accounted for the total number of words in the full text of the government work reports to represent the strength of the government's environmental governance.

Other control variables were the agricultural industrial structure (ainstru), agricultural public investment (pubinvestments), fiscal decentralization (fisexp), regional industrial structure (primarypro), and rural population proportion (rupoppro). The agricultural industrial structure was expressed by the proportion of the total output value of planting and animal husbandry in the total output value of agriculture, forestry, animal husbandry, and fishery, mainly considering that the carbon emissions generated by planting and animal husbandry in production activities are greater than those of other agricultural industrial sectors [53]. The public investment in agriculture was expressed by the investment amount of fixed assets in agriculture, forestry, animal husbandry, and fishery. Previous study has shown that an increase in fixed assets investment in agriculture, forestry, animal husbandry, and fishery plays a certain role in inhibiting agricultural carbon emissions [54]. Fiscal decentralization used a decentralized structure at the level of fiscal expenditure, expressed by the ratio of per capita provincial fiscal expenditure to the sum of per capita provincial fiscal expenditure and per capita central fiscal expenditure. The regional industrial structure was expressed by the proportion of the added value of the primary industry in the regional GDP. The proportion of the rural population was expressed by the proportion of the total rural population of the region to the total population of the region. The descriptive statistical results of each variable are shown in Table 1.

Table 1. Variable description and descriptive statistics.

Variable Name	Obs.	Measure	Mean	SD [a]	MIN	MAX
carbon	480	—	−1.462	1.453	−10.643	0.318
envpro	480	%	0.600	0.253	0.078	1.529
ainstru	480	%	0.825	0.104	0.540	0.960
fisexp	480	—	0.510	0.122	0.202	0.937
pubinves	480	100 million CNY	467.800	574.597	1.100	3814.470
primarypro	480	%	10.714	5.740	0.300	33.700
rupoppro	480	%	44.835	14.008	10.417	73.137

[a] SD = standard deviation.

4. Analysis of Empirical Results

4.1. Basic Regression Results

Table 2 shows the basic regression results of estimation based on spatial adjacency weight. Model 1 shows the estimation results of the spatial panel SAR model while model 2 shows the estimation results of the SDM model. In this paper, the likelihood ratio test (LR test) was used to compare and select the SAR model and the SDM model. The test results show that the likelihood ratio statistic was 36.320, and the corresponding *p*-value was 0.000.

Therefore, SAR could be rejected as a nested model of SDM, and the SDM model should be selected. In addition, this paper also used the Hausman test to verify the random and fixed effects of the spatial panel model. It can be seen from Table 2 that, in the SDM model, the *p*-value of the Hausman test was 0.000, rejecting the original hypothesis and choosing the fixed effect. The subsequent analysis of this paper is based on the fixed-effect panel SDM model. From the estimation results of model 2, it can be seen that the spatial autoregressive coefficient reflecting the strategic interaction of local governments was 0.131, and it was positive at the significance level of 5%, which indicates that local governments have positive competition with respect to the agricultural carbon peak, and they adopt a complementary carbon peak competition strategy. That is, when the carbon peak level of the surrounding provinces increases, the carbon peak level of the local region will also increase. There is a phenomenon of mutual imitation and convergence between the neighboring provinces. The root of this kind of competition strategy behavior lies in the driving force of local government competition incentives under the decentralization system, and this kind of competition mainly stems from political incentives. Local governments compete with each other strategically in order to gain advantages in performance assessment. This internal motivation drives them to attach importance to the agricultural carbon emission intensity index, as well as strive to improve the local carbon peak level. Therefore, under the decentralized system, the competition between local governments strengthens the local government's carbon reduction and emission reduction behavior.

Table 2. Strategic interaction estimation of local government's carbon peak goal.

Variable Name	Model 1 SAR			Model 2 SDM		
	Coefficient	**SE [a]**	**Z-Statistic**	**Coefficient**	**SE [a]**	**Z-Statistic**
ρ	0.163 ***	0.049	3.320	0.131 **	0.059	2.200
envpro	0.451 ***	0.076	5.910	0.467 ***	0.077	6.040
ainstru	−1.212 **	0.475	−2.550	−1.035 *	0.537	−1.930
fisexp	0.188	0.446	0.420	1.256 **	0.521	2.410
pubinves	−0.000 ***	0.000	−5.590	−0.000 ***	0.000	−5.680
primarypro	0.022 ***	0.008	2.630	0.014 *	0.008	1.700
rupoppro	−0.067 ***	0.005	−13.370	−0.050 ***	0.008	−6.360
W × envpro				−0.021	0.128	−0.170
W × ainstru				3.515 ***	0.838	4.200
W × fisexp				2.234 *	1.262	1.770
W × pubinves				0.000 ***	0.000	2.900
W × primarypro				−0.036 **	0.016	−2.300
W × rupoppro				−0.004	0.010	−0.390
Obs.		480			480	
Hausman test		10.530			38.070	
Hausman *p*-value		0.160			0.000	
LR Test χ^2			36.320			
LR Test *p*			0.000			

Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. [a] SE = standard error.

In Table 2, each independent variable coefficient of model 2 indicates the influence of each independent variable on the local agricultural carbon peak level. For the interpretation of the estimated coefficient of each independent variable, the conventional estimation coefficient interpretation method cannot be directly applied. It is necessary to further calculate the direct effect, indirect effect, and total effect of the relevant independent variables. The results are shown in Table 3. The direct effect in Table 3 is the sum of the spatial Dubin model coefficient and the feedback effect. The feedback effect indicates that the independent variable of a certain region will have an impact on the agricultural carbon peak level of its surrounding provinces, which, in turn, will affect the agricultural carbon

peak level of the region, which is also called the "regional spillover effect". The indirect effect is also called the "spatial spillover effect", indicating the impact of an independent variable of the surrounding provinces on the peak level of agricultural carbon in this region. The total effect is the sum of the direct effect and indirect effect, indicating the average impact of the change in an independent variable in a certain region on the peak level of agricultural carbon in all regions. By combining the results in Tables 2 and 3, the results of the respective variables can be explained in detail.

Table 3. Calculation results of direct and indirect effects.

Variable Name	LR_Direct		LR_Indirect		LR_Total	
	Coefficient	Z-Statistic	Coefficient	Z-Statistic	Coefficient	Z-Statistic
envpro	0.468 ***	6.390	0.072 **	2.530	0.540 ***	6.410
ainstru	−0.957 *	−1.800	3.652 ***	3.940	2.695 ***	2.620
fisexp	1.291 **	2.510	2.665 **	2.040	3.956 **	2.430
pubinves	−0.000 ***	−5.700	0.000 ***	3.000	−0.000	−0.170
primarypro	0.013	1.640	−0.037 **	−2.280	−0.024	−1.360
rupoppro	−0.051 ***	−8.210	−0.008 ***	−2.800	−0.059 ***	−9.160

Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

The spatial Dubin regression coefficient of environmental governance (envpro) in Table 2 was 0.467, showing a significant positive relationship with the local agricultural carbon peak level, indicating that a stronger environmental governance capacity is more conducive to the improvement of the local agricultural carbon peak level. In Table 3, the direct effect coefficient value of environmental governance (envpro) was 0.468, with a feedback effect of 0.002, indicating that a stronger local environmental governance ability is conducive to the improvement of the agricultural carbon peak level of neighboring provinces, and this impact will, in turn, promote the improvement of the local agricultural carbon peak level. The indirect effect coefficient of environmental governance (envpro) was 0.072, indicating that the environmental governance of neighboring provinces has a significant positive relationship with the local agricultural carbon peak level, along with a significant spatial spillover effect, whereby increasing environmental governance in neighboring regions is conducive to the improvement of the local agricultural carbon peak level. The direct effect coefficient of environmental governance (envpro) was significantly greater than the indirect effect coefficient, indicating that the impact of local environmental governance on the peak level of agricultural carbon is significantly greater than the impact of environmental governance of neighboring provinces on the peak level of local agricultural carbon. According to the coefficient of total effect, environmental governance (envpro) has a significant positive average impact on the peak level of agricultural carbon in all regions, whereby increasing environmental governance is conducive to the improvement of the peak level of agricultural carbon in all regions.

The spatial Dubin regression coefficient of the agricultural industrial structure (ainstru) was −1.085, which was significantly negatively related to the local agricultural carbon peak level. That is, a greater proportion of the total output value of local animal husbandry and planting industry in the output value of agriculture, forestry, animal husbandry, and fishery leads to greater agricultural carbon emissions and a more unfavorable promotion of the local agricultural carbon peak level. The indirect effect coefficient of the agricultural industrial structure (ainstru) was 3.652, passing the significance test at the level of 1%, indicating that the agricultural industrial structure has a significant spatial spillover effect on the peak level of agricultural carbon; i.e., there is a significant positive relationship between the agricultural industrial structure of adjacent areas and the local agricultural carbon peak level. According to the coefficient and direction of the total effect, the agricultural industrial structure (ainstru) has a significant positive average impact on the peak level of agricultural carbon in all regions.

The spatial Dubin regression coefficient of fiscal decentralization (fisexp) was 1.230, showing a significant positive relationship with the local agricultural carbon peak level, indicating that a higher local fiscal expenditure decentralization is more conducive to the improvement of the local agricultural carbon peak level. The indirect effect coefficient of fiscal expenditure decentralization (fisexp) was 2.665, indicating that the fiscal decentralization level of the neighboring provinces has a significant positive relationship with the local agricultural carbon peak level, along with a significant spatial spillover effect; i.e., a higher fiscal decentralization level in neighboring regions results in a better local agricultural carbon peak level. According to the coefficient and direction of the total effect, fiscal decentralization (fisexp) has a significant positive average impact on the peak level of agricultural carbon in all regions, whereby a higher degree of fiscal decentralization is more conducive to the improvement of the peak level of agricultural carbon in all regions.

The spatial Dubin regression coefficient of agricultural public investment (pubinves) was −0.000, which had a significant negative relationship with the local agricultural carbon peak level. That is, a greater local investment in fixed assets of agriculture, forestry, animal husbandry, and fishery is more unfavorable to the improvement of the local agricultural carbon peak level. A possible explanation is that fixed asset investment activities will cause additional carbon emissions, and, because the return period is long, this has little effect on the increase in agricultural output value in the short term. The direct effect coefficient of agricultural public investment (pubinves) indicates that the local agricultural public investment will further affect the realization of the local agricultural carbon peak target under the influence of a feedback effect, while the indirect effect coefficient indicates that the agricultural public investment of neighboring provinces has a positive impact on the agricultural carbon peak level of the region. Under the offset of direct and indirect effects, the negative average impact of agricultural public investment (pubinves) on the peak level of agricultural carbon in all regions was not significant.

The spatial Dubin regression coefficient of the regional industrial structure (primarypro) was 0.014, which had a positive relationship with the local agricultural carbon peak level, passing the significance test at the level of 10%. The direct effect coefficient of the regional industrial structure (primarypro) shows that the positive relationship between the proportion of the primary industry and the peak level of agricultural carbon was not significant. The indirect effect coefficient of the regional industrial structure (primarypro) was −0.037, indicating that the regional industrial structure of the neighboring provinces has a significantly negative relationship with the local agricultural carbon peak level, along with a significant spatial spillover effect, whereby the reduction in the proportion of the primary industry in the neighboring regions is conducive to the improvement of the local agricultural carbon peak level. Agriculture itself has two attributes with respect to carbon sinks and carbon emissions. Under the offset of direct and indirect effects, the negative average impact of the regional industrial structure (primarypro) on the peak level of agricultural carbon in all regions was not significant.

The spatial Dubin regression coefficient of the proportion of rural population (rupoppro) was −0.051, showing a significant negative relationship with the local agricultural carbon peak level; i.e., a smaller proportion of the local rural population is more conducive to the improvement of the local agricultural carbon peak level. The indirect effect coefficient indicates that the proportion of rural population (rupoppro) in the neighboring provinces has a significant spatial spillover effect on the peak level of agricultural carbon in the region, whereby a reduction in the proportion of the rural population in the neighboring provinces brings about an increase in the peak level of local agricultural carbon. According to the coefficient and direction of the total effect, the proportion of the rural population(rupoppro) has a significant negative average impact on the peak level of agricultural carbon in all regions, whereby a reduction in the proportion of the rural population is conducive to the improvement of the peak level of agricultural carbon in all regions. Generally speaking, the provinces with a high proportion of rural population are mostly large agricultural

provinces, and the agricultural carbon emissions are relatively high; hence, the peak level of agricultural carbon is lower than that of other provinces.

4.2. Robustness Analysis of Different Spatial Weights

In order to verify the robustness and reliability of the model estimation results, this paper used the spatial distance weight matrix, the distance square weight matrix, and the economic distance weight matrix to carry out regression analysis on the model. The setting method of each weight matrix form was previously described by Peng Xuhui et al. [44]. The estimation results are shown in Table 4. The Hausman test results show that the panel SDM model using fixed effects was supported under the three spatial weight matrices. Regardless of the spatial weight matrix used, the spatial autoregressive coefficient of agricultural carbon peak level was positive at the significance level of 1%. Local governments have obvious strategic complementary behaviors in competition with respect to the agricultural carbon peak level, and the interaction effect of this competition is very stable. According to the regression coefficient value, the spatial autoregressive coefficient based on the distance space weight matrix and the distance square space weight matrix is relatively large. This indicates that geographical factors are still the main factors to be considered in the local government's agricultural carbon peak strategy. When the local government interacts with the agricultural carbon peak strategy, it is still more inclined to take geographically adjacent regions as the yardstick. The spatial Dubin regression coefficient of environmental governance (envpro) changed little, and the results were also very stable.

Table 4. Strategic interaction estimation of local governments' carbon peak goals under different spatial weight matrices.

Variable Name	Weight of Distance		Weight of Distance Square		Weight of Economic Distance	
	Coefficient	**Z-Statistic**	**Coefficient**	**Z-Statistic**	**Coefficient**	**Z-Statistic**
ρ	0.395 ***	5.600	0.277 ***	3.720	0.136 ***	2.590
envpro	0.407 ***	5.450	0.399 ***	5.350	0.443 ***	6.040
ainstru	−1.676 ***	−3.440	−1.551 ***	−3.180	−2.494 ***	−5.070
fisexp	0.202	0.460	0.553	1.190	−0.254	−0.590
pubinves	−0.000 ***	−5.110	−0.000 ***	−5.350	−0.000 ***	−6.050
primarypro	0.028 ***	3.410	0.029 ***	3.550	0.033 ***	4.100
rupoppro	−0.065 ***	−10.910	−0.053 ***	−7.380	−0.060 ***	−10.870
Hausman test	17.960		16.880		21.960	
Hausman *p*-value	0.022		0.051		0.015	
Obs.	480		480		480	

Note: *** denotes statistical significance at the 1% level.

This paper also calculated the direct effect, indirect effect, and total effect of environmental governance and other control variables under different spatial weight matrices. The results are shown in Table 5. Under the three weight matrices, the direct effect, indirect effect, and total effect coefficient of environmental governance (envpro) were significantly positive. In addition, agricultural industrial structure (ainstru) and fiscal decentralization (fisexp) had a significant positive average impact on the peak level of agricultural carbon, and agricultural public investment (pubinves) and rural population proportion (rupoppro) had a significant negative average impact on the peak level of agricultural carbon. These results are in good agreement with the calculation results based on spatial adjacency weight, further indicating that the research conclusions of this paper are robust and that changes in the spatial weight matrix would not affect the main research conclusions of this paper.

Table 5. Calculation results of direct and indirect effects under different spatial weight matrices.

Variable Name		Envpro	Ainstru	Fisexp	Pubinves	Primarypro	Rupoppro
Weight of distance	LR_Direct	0.413 ***	−1.505 ***	0.189	−0.000 ***	0.028 ***	−0.065 ***
	LR_Indirect	0.271 ***	8.363 ***	0.142	−0.000 ***	0.019 **	−0.043 ***
	LR_Total	0.683 ***	6.858 ***	0.331	−0.000 ***	0.047 ***	−0.108 ***
Weight of distance square	LR_Direct	0.404 ***	−1.401 ***	0.544	−0.000 ***	0.029 ***	−0.054 ***
	LR_Indirect	0.152 **	4.018 ***	0.204	−0.000 **	0.011 **	−0.044 ***
	LR_Total	0.556 ***	2.617 **	0.747	−0.000 ***	0.040 ***	−0.098 ***
Weight of economic distance	LR_Direct	0.445 ***	−2.339 ***	−0.200	−0.000 ***	0.032 ***	−0.060 ***
	LR_Indirect	0.072 **	5.327 ***	2.682 **	−0.000 **	−0.071 ***	−0.010 **
	LR_Total	0.518 ***	2.988 ***	2.482 *	−0.000 ***	−0.040 **	−0.070 ***

Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

5. Discussion

This paper discussed the issue of agricultural carbon emissions in China under the background of introducing the goal of carbon peaking, which used the network game model to analyze the impact of environmental governance on the agricultural carbon peaking level from the theoretical level and the strategic interaction between local governments on the goal of agricultural carbon peaking, and we used the spatial econometric model to empirically test the conclusions drawn from the theoretical analysis. The theoretical and empirical analysis of this paper shows that environmental governance and local government competition play important roles in achieving the goal of agricultural carbon peak [11,15,17]. Previous studies have shown that there is a significant spatial correlation between carbon emissions [36,38,51,55–57], which indicates that carbon reduction and emission reduction cannot rely on the unilateral actions of various regions [43,58]. Local governments have positive competition in the competition for agricultural carbon peak, and there is mutual imitation and convergence between neighboring provinces [59,60]. Under the recognition of the common goal of reaching the carbon peak, all regions should strengthen environmental governance and attach importance to carbon emission reduction cooperation to promote carbon emission reduction at a lower cost [53,61–64].

Compared with the existing studies, the main contributions of this paper are reflected in two aspects. Firstly, most of the existing studies on agricultural carbon emissions are biased toward the construction of indicator systems and quantitative measurement analysis, with less focus on the government behavior driving factors behind agricultural carbon emissions. In this paper, on the basis of existing research, the driving mechanism and influencing factors of the agricultural carbon peak were systematically analyzed. Secondly, this paper creatively introduces the network game theory to analyze the impact of environmental governance on the agricultural carbon peak level and the effect of strategic interaction behavior among local governments on the agricultural carbon peak target. On the basis of theoretical analysis, these impacts are verified through the spatial econometric model, which represents an innovative approach in the literature.

It is undeniable that there are still some deficiencies in the theoretical analysis and empirical analysis of this work. In fact, straw burning is also one of the sources of agricultural carbon emissions [65]. However, it is difficult to estimate the quantity of straw burning accurately. Due to data limitations, this paper does not consider the carbon emissions caused by the open burning of crop residues when calculating the agricultural carbon emissions of various provinces in China. However, the agricultural carbon emission measurement system used in this paper fully considers the carbon emissions caused by animal breeding, rice planting, and energy input in agricultural production, which is scientific and reasonable. In the future, it is planned to further improve the measurement system of agricultural carbon emissions to reduce the error of research results.

6. Conclusions and Recommendations

6.1. Main Conclusions

This paper described the internal relationship among environmental governance, local government competition, and the peak level of agricultural carbon by introducing the network game model, as well as empirically analyzing the strategic interaction between local governments using the data of 30 provincial-level regions in the Chinese Mainland from 2005 to 2020 combined with the spatial measurement panel model, thus realizing the organic integration of theoretical analysis and empirical testing. The empirical analysis based on the spatial Dubin panel model found that there is a positive competition among local governments in the competition with respect to agricultural carbon peaks, and they adopt a complementary carbon peak competition strategy. That is, when the carbon peak level of the surrounding provinces increases, the carbon peak level of the local region will also increase. There is a phenomenon of mutual imitation and convergence between the neighboring provinces. Under different spatial weight matrix settings, the competitive interaction effects of local governments in agricultural carbon peak are stable and reliable, and the local governments are more inclined to take geographically adjacent regions as the yardstick in the competition with respect to agricultural carbon peak strategy. Secondly, environmental governance has a significant positive direct effect and a positive spatial spillover effect. Increasing environmental governance is conducive to the improvement of the local agricultural carbon peak level. Increasing environmental governance in neighboring provinces can also promote the improvement of the local agricultural carbon peak level. From the perspective of the coefficients, its direct effect is significantly greater than the spatial spillover effect. Therefore, more attention should be paid to local environmental governance to promote the improvement of the agricultural carbon peak level. Thirdly, agricultural industrial structures, fiscal decentralization, agricultural public investment, environmental governance, regional industrial structure, and the proportion of the rural population have significant spatial spillover effects. Agricultural industrial structure and fiscal decentralization are significantly positively correlated with the peak level of agricultural carbon, while the proportion of the rural population is significantly negatively correlated with the peak level of agricultural carbon.

6.2. Policy Implications

The theoretical and empirical analysis of this paper showed that environmental governance and local government competition play important roles in achieving the goal of agricultural carbon peak. In order to better achieve the goal of agricultural carbon peak and promote the high-quality development of agriculture, on the basis of the above research conclusions, this paper puts forward some policy recommendations.

Firstly, the cooperation and exchange of local governments in agricultural carbon emission reduction and the collaborative governance capacity of regional agricultural carbon emissions should be strengthened. An information transmission platform should be built for regional agricultural carbon emission control, and cooperation and exchanges among various regions should be strengthened, especially in neighboring regions. On the basis of considering the differences in the total amount and sources of agricultural carbon emissions in various regions, the emission reduction advantages of various regions can be considered. In the deployment of agricultural carbon emission policies, the interactive factors of spatial strategies, the demonstration role of typical regions, and the imitation of surrounding regions should be fully considered, while emphasizing regional linkage to improve the collaborative governance ability to reduce regional agricultural carbon emissions.

Secondly, efforts to improve agricultural environmental protection should be intensified. The mode of agricultural development should be changed while implementing the action of agricultural green development. The prevention and control mechanism of agricultural non-point source pollution should be improved while increasing investment in the treatment and restoration technology of polluted farmland, as well as improving the

utilization rate of chemical fertilizers and pesticides for crops. Collection points should be set up for pesticide packaging wastes while exploring multiple ways to recover them. Farmers should be guided to discard agricultural film and other production wastes to avoid "white pollution". The resource utilization of livestock and poultry breeding wastes should be accelerated while improving the supervision of livestock and poultry breeding pollution, as well as minimizing the pollution impact caused by livestock and poultry breeding wastes.

Thirdly, the agricultural industrial structure should be adjusted and optimized to a green and low-carbon transformation. On the basis of adhering to the bottom line of food security, the agricultural production structure should be adjusted and optimized while improving the level of agricultural industrialization, specialization, and agglomeration, as well as the agricultural production efficiency. The transformation of the agricultural production mode should be actively ushered from the traditional production mode of "high energy consumption, high emissions, high pollution, and low carbon sink" to the modern, low-carbon agricultural production mode of "low energy consumption, low emissions, low pollution, and high carbon sink". Investment in green and ecological agriculture should be increased while improving agricultural production infrastructure. The "three products and one standard" certification and brand building of agricultural products should be accelerated while improving the quality and popularity of local agricultural products. New modes and new paths of green agriculture whole-chain operation and management should be explored while extending the industrial chain, as well as improving the driving ability of the industrialized operation mode.

Fourthly, the role of fiscal policy should be fully considered in supporting and guiding the development of low-carbon agriculture. Financial input should be increased while giving appropriate policy preference to the development of green and low-carbon agriculture. Furthermore, the structure of financial subsidies for agriculture should be adjusted while guiding the vast number of agricultural practitioners to adopt low-carbon production methods through financial means, allowing them to effectively participate in the protection of arable land resources and ecological environment while constantly cultivating their habits of low-carbon production and low-carbon consumption.

Lastly, the efficiency of agricultural public investment should be improved. The structure of public investment in agriculture should be continuously optimized while increasing investment in agricultural infrastructure. The construction of agricultural projects such as high-standard farmland, the storage and preservation of agricultural products, and cold-chain logistics should be accelerated while constantly improving agricultural production conditions. The environment for public investment in agriculture should be improved, and the ability of regions to absorb public investment in agriculture should be enhanced. The supervision and regulation of agricultural public investment funds should be strengthened while constantly improving the efficiency of agricultural public investment.

Author Contributions: Conceptualization, Y.Y., X.P., and Y.T.; methodology, Y.Y. and X.P.; software, Y.Y., H.Y., and X.P.; formal analysis, Y.Y. and X.P.; resources, W.W.; data curation, Y.Y., H.Y., and M.Y.; writing—original draft preparation, Y.Y.; writing—review and editing, Y.T., X.P., and M.Y.; visualization, Y.Y.; supervision, Y.Y.; funding acquisition, Y.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the key scientific research projects of colleges and universities in Henan Province (no. 23A790025), National natural science foundation of China (no. 71903197; no. 71804059), Anyang science and technology plan soft science research project (no. 2022C02ZF013), and the Doctoral research startup fund project of Anyang Institute of Technology (no. BSJ2020001).

Institutional Review Board Statement: By convention, the Institutional Review Board (IRB) statement is exempted because (1) one of the authors has the job responsibility of collecting and handling the data; (2) the analysis was conducted on data anonymized by that author and thus imposed no risk; (3) our institutions have no IRB.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are available from the authors upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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ISBN 978-3-7258-0884-7