

Article

Driver or Deterrent? Deciphering the Impact of Agricultural New Quality Productive Forces on Non-Grain Production of Cultivated Land in the Yangtze River Basin

Zhanpeng Qu, Xinying Li, Siyuan Li, Shanni Wang, Yuanjie Wang and Yue Wang *

College of Economics, Sichuan Agricultural University, Chengdu 611130, China; 202301799@stu.sicau.edu.cn (Z.Q.); 202302018@stu.sicau.edu.cn (X.L.); 202302912@stu.sicau.edu.cn (S.L.); 202302584@stu.sicau.edu.cn (S.W.); 202402369@stu.sicau.edu.cn (Y.W.)

* Correspondence: wangyue@sicau.edu.cn

Abstract

Food security is a strategic national priority, yet the expansion of non-grain production of cultivated land (NGPC) poses a substantial threat to grain production capacity. This paper investigates whether agricultural new quality productive forces (ANQPFs)—as a potential high-quality solution to food security challenges—can effectively mitigate NGPC. Conceptually, while ANQPF may either promote or inhibit NGPC, its net effect remains indeterminate. Initially, an optimal decision-making model is developed to theoretically examine the influence of ANQPF on land-use strategies. Aligning with theoretical predictions, empirical estimates from two-way fixed effects models using Yangtze River Basin panel data (2013–2023) demonstrate that ANQPF significantly mitigates NGPC. These results are resilient to a battery of robustness and endogeneity tests. Mechanism analysis indicates that this effect operates through the substitution of traditional labor and the expansion of socialized services tailored to grain crops. This inhibitory effect is found to be more pronounced in major grain-producing regions and less developed areas. Notably, threshold regression reveals a non-linear relationship: the capacity of ANQPF to stabilize grain production diminishes as per capita GDP surpasses a critical threshold, exhibiting a pattern of diminishing marginal returns. The findings suggest that while ANQPF initially inhibits the shift toward non-grain production, its effectiveness is contingent and stage-dependent. This underscores the need for differentiated policy interventions that integrate technological innovation with institutional and economic support to safeguard food security.

Keywords: agricultural new quality productive forces; non-grain production of cultivated land; socialized services tailored to grain crops; threshold effect; differentiated policy interventions



Academic Editor: Vítor João Pereira Domingues Martinho

Received: 17 May 2026

Revised: 22 June 2026

Accepted: 1 July 2026

Published: 2 July 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

1. Introduction

As a cornerstone of national development and social stability, food security remains a paramount strategic priority [1]. However, despite its currently solid framework, China's food security system still faces evolving structural and resource-based pressures [2]. One of the most prominent issues lies in the tendency to utilize cultivated land resources [3]. While the Chinese government strictly prohibits the diversion of cultivated land toward non-grain uses (e.g., forestry or aquaculture), the agricultural sector is being reshaped by historic shifts in labor, demographics, and modernization. Consequently, the phenomenon of “non-grain production of cultivated land” (NGPC) is gradually emerging and becoming increasingly

severe. NGPC refers to the process of adjusting cultivated land use from growing grain crops to cultivating non-grain crops or engaging in other production activities such as forestry, livestock, and aquaculture. This process remains within the scope of agriculture and does not alter the agricultural designation of the land; rather, it constitutes an adjustment in production structure driven by internal comparative returns within agriculture [4]. The widespread shift toward NGPC undermines grain production capacity and challenges existing food security frameworks [5].

As the Chinese national economy pivots toward high-quality development [6], traditional agricultural productivity is being redefined. Driven by technological innovation and the integration of digital technologies, agricultural productivity is evolving into a new paradigm defined by green development and high efficiency [7], within which agricultural new quality productive forces (ANQPFs) have emerged. ANQPF originates from China's policy discourse on "new quality productive forces", but has since been conceptualized as a multidimensional construct grounded in Marxian productivity theory. ANQPF represents an innovation-driven form of agricultural productivity, underpinned by scientific and technological advances and characterized by the intelligent and green transformation of laborers, objects of labor and means of labor [8]. In essence, ANQPF reflects a system-level transformation of agricultural production, capturing the overall upgrading and reconfiguration of production factors and the modernization of agricultural production systems. It provides an integrated representation of productivity enhancement driven by technological progress, labor quality improvement, and organizational innovation, rather than any single dimension in isolation. Against this background, the Chinese government has prioritized the development of high-quality rural human capital, the upgrading of agricultural infrastructure, and the establishment of modern agricultural management systems [9]. Consequently, ANQPF has become an important guiding concept shaping the future trajectory of agricultural development in China.

In the process of agricultural modernization, the development of ANQPF can significantly improve agricultural productivity and increase the yields of both grain and non-grain crops, thereby promoting agricultural development and enhancing the overall performance of the agricultural sector [10]. More importantly, the development of ANQPF may also influence farmers' production decisions by altering production costs, expected returns, and resource allocation patterns. As farmers adjust their crop choices in response to these changes, the planting structure of cultivated land may consequently be reshaped. The potential mechanisms can be discussed from the following perspectives. On the one hand, in countries with relatively developed productive forces, the production of grain crops is characterized by a high degree of mechanization and scale [11]. The development of ANQPF replaces traditional human labor with intelligent equipment and precise operations, reducing the absolute reliance of agricultural production on the number of laborers. This trend not only alleviates the pressure of agricultural labor shortage but also promotes the concentration of cultivated land utilization towards grain crops that are more suitable for large-scale and standardized production [12]. Objectively, it provides structural support for stabilizing the sown area of grain. On the other hand, the development of ANQPF, through technological penetration and organizational innovation, has given rise to new types of agricultural business entities, achieved the scale of agricultural socialized services, and promoted the integration of the agricultural industrial chain [13]. The economies of scale and network effects driven by socialized services are more suitable for the cultivation of grain crops that have the attributes of measurable division of labor and field operations [12,14]. Therefore, agricultural socialized services can particularly reduce the production cost of grain crops, thereby changing farmers' production decisions. The above evidence indicates that the development of ANQPF can influence the decision-making on

the planting structure of cultivated land from two perspectives: labor force substitution and socialized services. Although China's foundation for food security is relatively solid, the increasingly severe trend of NGPC has also exerted certain pressure to further develop ANQPF. Therefore, clarifying the impact of the development of ANQPF on the grain planting structure of cultivated land and conducting an analysis of the path mechanism of this impact can provide necessary theoretical support and decision-making basis for promoting the modernization of agriculture and maintaining food security. This paper draws on a long panel dataset of 115 prefecture-level cities in the Yangtze River Basin from 2013 to 2023 to examine the impact of ANQPF on NGPC, as well as the underlying mechanisms and nonlinear characteristics.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature on ANQPF and NGPC and identifies the research gap. Section 3 presents the theoretical analysis and discusses the potential mechanisms. Section 4 introduces the variables, data, and identification strategy. Section 5 reports the benchmark regression results, mechanism analysis, and a series of robustness and endogeneity tests. Section 6 examines the heterogeneous and non-linear effects of ANQPF through subgroup regressions and threshold analyses. Section 7 concludes the study and discusses the corresponding policy implications. Finally, Section 8 presents future prospects and provides a discussion from an international perspective.

2. Literature Review

Research on ANQPF can be broadly classified into three strands. The first focuses on its theoretical connotations and development pathways. Existing studies generally regard ANQPF as a new stage of agricultural productivity development characterized by technological innovation, factor upgrading, and organizational transformation [15,16]. The second strand examines the measurement and spatiotemporal evolution of ANQPF. Using various indicator systems, scholars have evaluated regional differences, development trends, and coordination levels of ANQPF across China, finding that its overall level has steadily increased despite persistent regional disparities [17,18]. The third strand investigates the economic and social effects of ANQPF. Existing evidence suggests that ANQPF contributes positively to rural digitalization, high-quality agricultural development, and agricultural modernization [19,20]. Although these studies examine different development outcomes, they generally reach a consistent conclusion that ANQPF serves as an important driver of agricultural transformation and rural development. Overall, existing studies have established a solid understanding of the conceptual foundations, measurement approaches, and developmental outcomes of ANQPF. However, existing studies have primarily focused on the role of ANQPF in promoting agricultural modernization, rural digitalization, and high-quality agricultural development, whereas its implications for cultivated land-use decisions, particularly the allocation between grain and non-grain crops, remain insufficiently explored.

Research on NGPC can also be grouped into three main strands. The first examines its spatiotemporal patterns and evolution. Existing studies have documented significant spatial differentiation in NGPC across China and have analyzed changes in cultivated land use and grain production potential over time [21–24]. These studies generally find that the level of NGPC has fluctuated but exhibited an overall upward trend in recent years, with substantial regional variation. The second strand focuses on the determinants of NGPC. From the perspectives of natural endowments, location conditions, socioeconomic development, and policy interventions, scholars have identified a range of factors shaping different forms of non-grain production [25,26]. Despite differences in research perspectives, existing studies generally agree that NGPC is shaped by the joint influence of

natural, economic, and institutional factors. The third strand investigates the relationships between NGPC and other agricultural or socioeconomic phenomena, linking NGPC to factors such as cultivated land intensification, environmental impacts, land renting-in, and urbanization [27–30]. Overall, the existing literature has generated valuable insights into the spatial evolution, driving forces, and associated effects of NGPC. However, most studies emphasize the roles of resource endowments, market incentives, and institutional factors, while relatively limited attention has been paid to how changes in agricultural productivity systems may influence farmers' cropping decisions and the evolution of NGPC.

Taken together, the existing literature has substantially advanced our understanding of both the developmental effects of ANQPF and the determinants of NGPC. Existing studies have not only clarified the conceptual foundations, measurement approaches, and socioeconomic implications of ANQPF, but have also identified the spatiotemporal characteristics and driving forces of NGPC across different regions and contexts. Empirically, existing studies have predominantly relied on regional panel datasets, composite index construction methods, spatial analysis techniques, and econometric models to examine either the developmental effects of ANQPF or the determinants of NGPC. Although these studies have generated valuable findings, they have generally examined ANQPF and NGPC as separate research topics and the two research streams remain largely disconnected. On the one hand, studies on ANQPF have primarily focused on its implications for agricultural modernization and development outcomes, with limited attention paid to cultivated land-use decisions and cropping structure adjustment. On the other hand, while the NGPC literature has identified a variety of influencing factors, including resource endowments, institutional arrangements, Internet use, and agricultural mechanization [31,32], it has rarely examined cultivated land-use change from the broader perspective of ANQPF. Furthermore, although existing studies have emphasized the importance of technological progress and socioeconomic factors in shaping agricultural production [33,34], relatively little is known about whether the development of ANQPF influences the allocation between grain and non-grain crops and through which potential channels such effects may operate.

To address these gaps, this study incorporates ANQPF and NGPC into a unified analytical framework. Specifically, it combines theoretical analysis and empirical examination to investigate the impact of ANQPF on NGPC, thereby providing new evidence on the relationship between agricultural productivity transformation and cultivated land-use decisions. Building upon this research gap, the marginal contributions of this study are summarized below.

First, this study provides substantive evidence on the relationship between ANQPF and NGPC by examining how the development of ANQPF affects cultivated land-use decisions. Existing research has extensively examined the theoretical connotations and development pathways of ANQPF [15,16], as well as their impacts on agricultural high-quality development [20] and rural digitalization [19]. Meanwhile, a substantial body of research has explored the spatiotemporal patterns and driving factors of NGPC from natural, economic, and policy perspectives [21–28]. However, against the backdrop of safeguarding national food security, studies integrating the concept of ANQPF with the issue of NGPC remain scarce. This study extends the literature on ANQPF by shifting the analytical focus from macro development outcomes to micro land-use configurations.

Second, this study makes a methodological contribution by integrating theoretical modeling with empirical measurement to elucidate the underlying mechanisms between ANQPF and NGPC. While previous studies have largely emphasized the effects of specific technologies or macro-level technical progress, this study incorporates ANQPF into a farmer decision-making model. By examining the channels of labor substitution and socialized agricultural services, we analyze how ANQPF potentially shapes crop allocation

decisions. At the empirical level, we develop a multidimensional index for ANQPF and substantiate our findings via extensive robustness and endogeneity tests, including a “plausibly exogenous” IV approach to mitigate potential instrument invalidity. By bridging theoretical modeling with rigorous empirical validation, this study establishes a comprehensive framework for examining the link between ANQPF and NGPC.

Third, this study contributes from a policy perspective by examining the heterogeneous and non-linear effects of ANQPF on NGPC. While existing studies generally emphasize the positive role of technological progress in agricultural development [31,34], the effects of ANQPF may vary across regions with different policy designation and economic development levels. To account for these differences, this study conducts heterogeneity analyses based on regional policy designation and economic development. In addition, non-linear tests are employed to explore how the effects of ANQPF evolve across different stages of development. By identifying the conditions under which ANQPF exerts varying influences on NGPC, this study provides empirical evidence for designing policies aimed at promoting food security and sustainable agricultural development.

3. Theoretical Analysis and Research Hypotheses

3.1. Theoretical Framework of Farmers’ Production Decision-Making

To examine the potential mechanisms through which ANQPF may influence farmers’ crop allocation decisions and NGPC, this study develops a stylized farmer decision-making framework drawing on existing household production models [35]. The following simplifying assumptions are introduced to facilitate the analysis:

- (1) Farmers only consider how to optimize the allocation of household production factors to achieve maximum income.
- (2) There is no preference difference among farmers regarding the types of crop varieties or the choice of planting methods.
- (3) There is no difference in the economic specialization among farmers when they produce different crops [36,37]. This implies that farmers do not acquire crop-type-specific specialization from past planting that would systematically affect their current crop allocation decisions.
- (4) The inputs for farmers’ agricultural production are primarily land and labor. Agricultural socialized services can facilitate farmers’ production activities by providing mechanized, specialized, and organized support for agricultural operations. In addition, farmers may adjust their operational scale through land transfer to expand production scale and improve resource allocation efficiency.

Suppose a representative household whose objective function is to pursue the maximization of total household income U :

$$\text{Max}U = Y_1 + Y_2 + W - R - S, \quad (1)$$

where Y_1 represents the total output value of grain crops after considering the basic planting cost, Y_2 denotes the total output value of non-grain crops (cash crops) after taking into account the basic planting cost, W stands for the wage income of non-agricultural workers in the family, R signifies the rental cost of the net transfer of farmland, and S indicates the total cost of purchasing socialized services.

Drawing on existing study [34], the production of grain and non-grain crops is represented by the following functional form:

$$Y_1 = p_1(A_1L_1)^\alpha, \quad (2)$$

$$Y_2 = p_2(A_2L_2)^\alpha, \quad (3)$$

where A_1 and A_2 respectively represent the land areas for growing grain crops and non-grain crops. L_1 and L_2 respectively stand for the total effective labor input into grain and non-grain production. p_1 and p_2 denote the unit output prices of grain and non-grain crops after taking into account the basic planting costs. α signifies the output elasticity of the production function, which is reflected in the degree of specialized economy in the production of two crops.

The land constraints for farmers are specified as follows:

$$A_1 + A_2 = 1 + A_3. \quad (4)$$

The endowment of farmers' own land is standardized to 1, and A_3 represents the net area of agricultural land transferred by farmers.

Farmers' labor allocation is governed by the following total labor availability constraint:

$$L_1 + L_2 + L_3 = 1, \quad (5)$$

where L_1 and L_2 respectively stand for the total effective labor input into grain and non-grain production, and L_3 represents the total household labor input into non-agricultural employment.

Equation (5) implicitly assumes homogeneous labor effectiveness across different production activities, treating labor input as fully comparable across crop types. However, grain crops and non-grain crops exhibit systematic differences in labor requirements and task characteristics. Grain production is typically associated with large-scale cultivation, relatively uniform production cycles, and a higher degree of mechanization and standardization, which allows labor inputs to be more efficiently organized and substituted by machinery services. In contrast, non-grain production is characterized by more heterogeneous production tasks, finer field management, and greater dependence on manual labor, implying a lower degree of labor substitutability [11].

To capture this substitutability in labor effectiveness within a unified household labor constraint, a labor adjustment parameter δ is introduced to rescale labor input in grain production relative to non-grain production. Accordingly, the original labor constraint in Equation (5) is reformulated, while preserving total labor endowment.

$$\delta L_1 + L_2 + L_3 = 1. \quad (6)$$

The non-agricultural wage income of farmers is as follows:

$$W = wL_3, \quad (7)$$

where w denotes the exogenous non-farm market wage rate.

The net rental cost for a household participating in the land transfer market is modeled as:

$$R = rA_3, \quad (8)$$

where r represents the land rent rate and A_3 indicates the net area of farmland transferred by farmers.

Suppose that the labor consumption in the production of grain crops and non-grain crops is a linear function with respect to the planting area:

$$L_1 = \rho_1 A_1, \quad (9)$$

$$L_2 = \rho_2 A_2, \quad (10)$$

where ρ_1 and ρ_2 stand for the labor consumption coefficients per unit of grain crops and non-grain crops, respectively.

The costs of obtaining agricultural social services vary across crop types because of differences in production standardization, operational complexity, and market accessibility. To capture this heterogeneity, the per-unit service costs associated with grain and non-grain production are denoted by

$$S = s_1 A_1 + s_2 A_2, \quad (11)$$

where S denotes the total cost of agricultural socialized services, s_1 represents the per-unit service cost in grain production, and s_2 represents the per-unit service cost in non-grain production.

By combining the above equations, we obtain:

$$U = w \cdot [1 - \delta \rho_1 A_1 - \rho_2 A_2] + [p_1 \rho_1^\alpha A_1^{2\alpha} + p_2 \rho_2^\alpha A_2^{2\alpha}] - [s_1 A_1 + s_2 A_2] - r A_3. \quad (12)$$

When the transfer of farmland to Scale A_3 is treated as exogenously given, solve for the partial derivative of U with respect to A_1 :

$$\partial U / \partial A_1 = 2\alpha p_1 \rho_1^\alpha A_1^{2\alpha-1} - 2\alpha p_2 \rho_2^\alpha A_2^{2\alpha-1} - \delta \rho_1 w + \rho_2 w + s_2 - s_1. \quad (13)$$

In order for farmers to increase the area planted with grain crops, it is necessary to satisfy:

$$\partial U / \partial A_1 > 0. \quad (14)$$

By rewriting Equation (14), we obtain:

$$Y_1 / A_1 - Y_2 / A_2 > [\delta \rho_1 w - \rho_2 w + s_1 - s_2] / 2\alpha. \quad (15)$$

The left-hand side of Equation (15) represents the relative marginal revenue from growing grain per unit of land, whilst the right-hand side represents the marginal switching cost threshold for switching to grain cultivation. Therefore, farmers' crop allocation decisions are ultimately determined by the comparison between expected returns and the corresponding cost threshold on the right-hand side of Equation (15). Specifically, when the relative marginal revenue is taken as given in the short run, optimal land allocation depends on whether the marginal switching cost threshold is sufficiently low to make grain production more attractive. Let this threshold term be denoted as C , where C captures the marginal cost threshold associated with switching from non-grain to grain cultivation.

$$C = \delta \rho_1 w - \rho_2 w + s_1 - s_2, \quad (16)$$

The sign of Equation (16) is not determined within the model, as the marginal cost threshold depends on the relative magnitude of multiple underlying mechanisms. In particular, C summarizes the net outcome of labor adjustment effects in grain production and differential changes in agricultural socialized service costs between grain and non-grain cropping systems. These channels may vary in both direction and intensity due to structural differences in production technologies, such as mechanization compatibility, production standardization, and the development of service markets.

To better understand the economic content of C , the following section decomposes this term into two distinct transmission channels. This decomposition builds on empirical regularities documented in the agricultural development literature, particularly in relation to labor-saving technological change and the diffusion of agricultural socialized services in China.

3.2. Mechanism of ANQPF Affecting Crop Allocation Decisions

Building on the decomposition of the marginal cost threshold in Equation (16), this section further examines how heterogeneity across cropping systems shapes farmers' re-

sponse to agricultural production conditions. In particular, crop allocation decisions are jointly determined by differences in production organization, labor task characteristics, and the degree of service market development across grain and non-grain crops.

Existing literature provides several relevant conclusions. Studies show that production systems differ in their organizational forms and specialization patterns across activities [36,37]. Empirical evidence further indicates that continuous plot management, larger operational scales, and reduced land fragmentation are associated with higher production standardization and improved mechanization efficiency. In particular, grain production systems tend to benefit more from land consolidation and scale expansion, as these factors improve machinery utilization and production continuity [38,39]. In addition, mechanization has been found to generate more significant productivity gains in grain crops, reflecting differences in their compatibility with standardized and mechanized production systems [40].

Let σ_1 denote the structural standardization index of grain crops and σ_2 denote the structural standardization index of non-grain crops, with σ_i capturing crops' compatibility with mechanized and standardized production practices, including plot scale and contiguity, production cycle uniformity, task standardization and mechanization suitability. According to the findings of a substantial body of literature [12,38–40], grain crops exhibit higher σ values:

$$\sigma_1 > \sigma_2 > 0 \quad (17)$$

These structural differences imply that the impact of agricultural modernization across different cropping systems is inherently heterogeneous. Differences in production standardization and mechanization compatibility suggest that any system-wide improvement in agricultural productivity will not be uniformly translated into effective production gains, but will instead be mediated by crop-specific structural conditions.

In the context of rural China, such system-wide improvements are typically embodied in ANQPF. These forces arise from the coordinated upgrading of agricultural labor, production inputs, and technological means. At this stage, ANQPF should not be interpreted as a specific production input, but rather as a conceptual background factor operating at the macro level, which activates and amplifies existing structural characteristics within agricultural production systems.

Accordingly, the role of ANQPF will be introduced in the following subsections through their interaction with crop-specific structural characteristics, allowing the model to capture how ANQPF reshapes labor substitution and social service cost structures in grain and non-grain production systems.

3.2.1. Labor Substitution Channels

Empirical evidence from agricultural mechanization and digital agriculture suggests that the extent to which modern production systems can substitute for manual labor depends jointly on technological intensity and crop standardization. Existing literature has extensively demonstrated that ANQPF, as a comprehensive force embodying the deep integration of digital technology, intelligent equipment, and standardized management, brings about features such as digital agriculture, upgraded agricultural machinery, and normalized production processes—key indicators of agricultural modernization [7,8,10]. In production tasks characterized by high structuralization and significant scaling, the application of ANQPF is more efficient, enabling it to fully play its role in replacing and supporting agricultural operations.

In addition, significant heterogeneity exists across cropping systems in terms of labor substitutability. Grain crops are generally characterized by larger operational scale, higher production standardization, and stronger mechanization compatibility, which make

their production processes more suitable for labor-saving technological substitution under modern agricultural systems. By contrast, cash crops are typically more labor-intensive, involving finer field management, more heterogeneous production tasks, and lower degrees of standardization, which limit the extent to which labor can be effectively replaced by modern agricultural technologies. As a result, ANQPF tends to generate stronger labor-substituting effects in grain production compared to non-grain production [12].

Accordingly, the proportion of production tasks that can be effectively replaced or supported by modern agricultural systems can be expressed as:

$$\tau_i(Q) = \sigma_i Q \quad (18)$$

where $\tau_i(Q)$ represents the task substitution rate. Q is the composite index of ANQPF, reflecting the overall level of systemic transformation in agricultural production. For analytical tractability, we adopt a linear specification capturing the first-order effect of ANQPF. This formulation implies that the marginal effect of ANQPF is amplified in production systems with higher structural compatibility.

Given the task substitution mechanism, the effective labor requirement per unit of land for crop i is defined as the non-substitutable portion of production tasks:

$$l_i(Q) = \rho_i [1 - \tau_i(Q)] = \rho_i (1 - \sigma_i Q) \quad (19)$$

where ρ_i denotes the baseline labor requirement per unit of land in the absence of ANQPF. The term $(1 - \sigma_i Q)$ captures the reduction in effective labor demand resulting from the diffusion of modern agricultural systems.

To characterize relative labor intensity between grain and non-grain production, the labor adjustment parameter is defined as:

$$\delta = l_1 / l_2 \quad (20)$$

By combining Equations (19) and (20), we obtain:

$$\delta = \rho_1 (1 - \sigma_1 Q) / \rho_2 (1 - \sigma_2 Q) \quad (21)$$

This expression shows that the relative labor requirement between grain and non-grain production is jointly determined by baseline labor intensity and heterogeneous responsiveness to ANQPF-induced structural transformation.

Differentiating Equation (21) with respect to Q yields:

$$d\delta/dQ = \rho_1 (\sigma_2 - \sigma_1) / \rho_2 (1 - \sigma_2 Q)^2 \quad (22)$$

Since $\sigma_1 > \sigma_2 > 0$, we find that $d\delta/dQ < 0$.

This result indicates that ANQPF reduces the relative labor requirement of grain production more strongly than that of non-grain production. In other words, ANQPF induces an asymmetric labor-saving effect across cropping systems, thereby altering the internal labor allocation structure within farm households and reshaping comparative advantages between grain and non-grain production.

From an aggregate perspective, this asymmetric labor-saving effect leads to a reduction in the overall agricultural labor demand, as the productivity improvements enabled by ANQPF reduce the total effective labor required for crop production. Consequently, the agricultural labor force contracts. Given that grain production is more compatible with standardized and mechanized operations, a shrinking labor supply imposes weaker constraints on grain cultivation than on labor-intensive cash crops. Thus, through the channel of agricultural labor force reduction, ANQPF systematically shifts farmers' comparative advantage toward grain production and suppresses NGPC.

3.2.2. Social Service Cost Channels

The second mechanism through which ANQPF affects farmers' crop allocation decisions operates via agricultural socialized service markets. Unlike labor input, which is primarily constrained within the household, service inputs are mediated through marketized outsourcing systems, including machinery services, pest control, irrigation, harvesting, and digital agricultural platforms.

Empirical studies on agricultural service outsourcing in China show that the development of agricultural mechanization and digital platforms has fundamentally changed the pricing and cost structure of agricultural services by improving service matching efficiency, reducing transaction costs, and enabling large-scale service provision [13,14].

Within this context, ANQPF is understood as a structural force that enhances the efficiency of agricultural service supply by improving three interconnected dimensions: (i) service provider capability through new agricultural laborers, (ii) service operability through improved agricultural objects of labor, and (iii) service delivery efficiency through advanced agricultural means of labor such as intelligent machinery and digital coordination platforms [41]. These improvements reduce the per-unit cost of providing agricultural services; however, the magnitude of cost reduction is not uniform across crops.

Specifically, grain production exhibits stronger compatibility with standardized service systems due to its large-scale cultivation patterns, relatively uniform agronomic requirements, and high degree of spatial continuity. These characteristics allow service providers to exploit economies of scale and learning-by-doing effects more effectively in grain production.

By contrast, non-grain crops such as fruits and vegetables are characterized by heterogeneous production conditions, fragmented plots, and more complex agronomic operations, which increase coordination costs and reduce the efficiency gains from service standardization [12–14].

Drawing on the above empirical findings, the per-unit service cost for crop i is expressed as follows:

$$S_i = s_0 - \mu\sigma_i Q, \mu > 0 \quad (23)$$

where s_0 denotes the baseline service cost in the absence of ANQPF and μ captures the overall efficiency improvement in agricultural service provision induced by system-wide modernization. Taking derivatives with respect to Q , we obtain:

$$ds_1/dQ = -\mu\sigma_1 \quad (24)$$

$$ds_2/dQ = -\mu\sigma_2 \quad (25)$$

Therefore, the differential effect of ANQPF on service costs across crops is given by:

$$ds_1/dQ - ds_2/dQ = -\mu(\sigma_1 - \sigma_2) \quad (26)$$

Since $\mu > 0$, $\sigma_1 > \sigma_2 > 0$, we find that $ds_1/dQ - ds_2/dQ < 0$.

This result indicates that ANQPF reduces service costs more strongly in grain production than in non-grain production, thereby widening the relative cost advantage of grain cultivation.

3.2.3. Integrated Effect of ANQPF on NGPC

Building on the above two channels, the marginal switching cost threshold C defined in Equation (16) can be further decomposed into its structural components. Substituting the labor adjustment parameter $\delta(Q)$ in Equation (21) and the service cost structure in Equation (23), the cost threshold becomes explicitly dependent on ANQPF:

$$C(Q) = \delta(Q)\rho_1 w - \rho_2 w + s_1(Q) - s_2(Q), \quad (27)$$

Taking the total derivative of $C(Q)$ with respect to Q , we obtain:

$$dC(Q)/dQ = \delta'(Q)\rho_1 w + s_1'(Q) - s_2'(Q) \quad (28)$$

As shown in Sections 3.2.1 and 3.2.2, the labor substitution channel implies that $\delta'(Q) < 0$, reflecting that ANQPF reduces relative labor requirements in grain production more strongly than in non-grain production. Meanwhile, the service cost channel implies that $s_1'(Q) - s_2'(Q) < 0$, indicating that service cost reductions are also more pronounced in grain production.

Therefore, both channels jointly reinforce each other, leading to:

$$dC(Q)/dQ < 0 \quad (29)$$

This result implies that ANQPF systematically reduces the marginal switching cost threshold for grain cultivation relative to non-grain crops. It operates as a structural transformation factor that reshapes relative factor prices and effective production costs across heterogeneous cropping systems.

Now, for the initial optimal area for grain cultivation A_1^* :

$$Y_1/A_1 - Y_2/A_2 = C(Q)/2\alpha. \quad (30)$$

When Q increases to Q^* :

$$C(Q^*) < C(Q), \quad (31)$$

$$Y_1/A_1^* - Y_2/A_2^* > C(Q^*)/2\alpha. \quad (32)$$

Equation (32) implies that, under the existing cropping pattern, the marginal profit from increasing grain production becomes positive. According to the principle of optimization, farmers will adjust A_1^* so that the new marginal condition returns to zero. Consequently, the new optimal grain area A_1^{**} satisfies:

$$A_1^{**} > A_1^*, \quad (33)$$

$$\partial A_1^*/\partial Q > 0. \quad (34)$$

Therefore, the improvement of ANQPF (Q) will lead farmers to expand the area of grain cultivation. Under the exogenous given condition of the transferred area A_3 of agricultural land, the sum of the area planted with grain and the area planted with non-grain crops is a constant value. The expansion of grain planting area will lead to a decrease in the planting area of non-grain crops, which in turn will cause a reduction in NGPC. Based on the above theoretical analysis, this paper puts forward Hypotheses as follows:

Hypothesis 1. *The advancement of ANQPF can significantly mitigate the level of NGPC.*

Hypothesis 2a. *The improvement of ANQPF mitigates NGPC by reducing the scale of agricultural labor force.*

Hypothesis 2b. *The improvement of ANQPF mitigates NGPC by enhancing the level of agricultural socialized services.*

4. Materials and Methods

4.1. Sample Selection and Data Sources

This paper takes the panel data of 115 prefecture-level city units in the Yangtze River Basin of China from 2013 to 2023 as the research sample, with a total of 1265 observed values. The prefecture-level city units in the Yangtze River Basin of China have the strategic position of major grain-producing areas, the typicality of the problem of NGPC, and the significant gradient of the development of ANQPF within the region, providing an ideal sample for in-depth analysis of the relationship between the two under the control of large-scale differences in natural conditions.

The relevant data in this article is sourced from China Statistical Yearbook, China Population and Employment Statistical Yearbook, China City Statistical Yearbook, China Statistical Yearbook on science and technology, as well as the statistics yearbooks of each prefecture-level city. Some of the data is supplemented through the Digital Economy Open Research Platform. The proportion of missing observations is small and does not show systematic patterns across variables or time, so most key variables are nearly fully observed. Given the smooth evolution of socio-economic indicators, missing values are imputed using linear interpolation method. All statistical analyses are performed using Stata software (version 18.0).

4.2. Variable Selection

4.2.1. Explained Variable

The explained variable in this paper is the level of NGPC. It reflects the change in the agricultural production structure, namely the agricultural planting structure gradually shifting from growing grain crops to growing cash crops. Scholars have reached a consensus on the definition of NGPC, and its severity is usually quantified by the proportion of non-food crop planting area. Referring to the practices in relevant literature [5,42], the level of NGPC in this paper is characterized by the proportion of non-grain crop sown area to the total sown area of crops. The grain crops mentioned in this article mainly include rice, tubers and legumes, while the non-grain crops include peanuts, vegetables, fruits and melons, etc. The calculation formula for the level of NGPC is expressed as follows:

$$\text{NGPC} = \text{N/C} \times 100\%, \quad (35)$$

where N represents the area sown with non-grain crops and C stands for the total area sown with crops.

4.2.2. Core Explanatory Variable

The core explanatory variable of this paper is ANQPF. Drawing on the Marxist theory of productive forces, agricultural productive forces are traditionally understood as the combination of agricultural laborers, agricultural means of labor, and agricultural objects of labor [43–45]. Within this classical framework, the three elements constitute a relatively static structure of production conditions.

Building on this foundation, the theory of ANQPF extends the traditional framework by emphasizing that productive forces are no longer determined solely by the quantity of individual elements, but increasingly depend on their systemic interaction and coordinated upgrading under technological progress [46]. In this sense, ANQPF should be understood as a transformation from isolated factor improvement to integrated system efficiency enhancement, where technological innovation reshapes the matching efficiency, substitution elasticity, and interaction structure among production factors [44,45].

Specifically, agricultural laborers are upgraded through improvements in human capital, digital literacy, and organizational capacity; agricultural objects of labor are transformed through land consolidation, ecological restoration, and improved production conditions, reflecting the active remediation and optimization of the natural environment; and agricultural means of labor are enhanced via the adoption of mechanization, digitalization, and intelligent technologies. The key innovation of ANQPF lies not in any single dimension, but in the synergistic reinforcement among these three components, which jointly improves the efficiency of factor combination and the overall productivity of the agricultural production system. It represents a shift from factor-based productivity to system-based productivity enhancement driven by technological innovation [10,15,16].

Following this interpretation and existing studies [43–45,47,48], this paper constructs an evaluation index system for ANQPF from three dimensions: new agricultural laborers, new agricultural objects of labor, and new agricultural means of labor. These dimensions jointly capture the transformation of agricultural productive forces in terms of improvement in labor quality, upgrading of material technologies, modernization of production conditions, and green development. The evaluation index system for ANQPF is shown in Table 1.

Table 1. ANQPF index system.

Indicator Category	Index	Definition and Description	Measuring Unit	Expected Sign
New agricultural laborers	Educational level of workers	The proportion of full-time teachers with a bachelor's degree or above in rural compulsory education schools	%	+
	Output value of laborers	Total output value of agriculture, forestry, animal husbandry and fisheries/Number of people employed in agriculture, forestry, animal husbandry and fisheries	10,000 CNY per person	+
	Income of workers	Per capita disposable income of rural residents	CNY	+
New agricultural objects of labor	Ecological protection	Rural greening rate	%	+
		Proportion of administrative villages treating domestic wastewater	%	+
		Proportion of administrative villages that treat household waste	%	+
	Pollution abatement	Comprehensive utilization rate of livestock and poultry manure	%	+
		Total amount of fertilizer applied	ton	–
New agricultural means of labor	Agricultural infrastructure	Total power of agricultural machinery	kilowatt	+
		Percentage of village roads that have been paved	%	+
		Peking University Inclusive Finance Index	/	+
	Agricultural insurance payouts	Agricultural insurance loss ratio	%	+
	Energy use	Total electricity consumption in rural areas	kilowatt-hour	+
	Sci-tech innovation	Number of agricultural technology patents	/	+

4.2.3. Control Variables

To alleviate the bias in test results caused by the existence of omitted variables, this paper refers to relevant studies [3–5] and comprehensively considers other factors that may affect the degree of NGPC, controlling the following factors that may affect the degree of NGPC in the region.

- (1) The urbanization rate (Urb) may influence cropping structure through land competition and changes in food demand. It is measured by the ratio of the permanent urban resident population to the total population of the region.
- (2) The level of opening up to the outside world (Open) may affect the regional cropping structure through export-oriented agricultural production. It is measured by the logarithm of the total volume of regional imports and exports.
- (3) The level of foreign direct investment (Fdi) may influence agricultural production patterns and cropping decisions. It is measured by the logarithm of the foreign direct investment amount.
- (4) Annual precipitation (Pre) is a key climatic factor that affects crop suitability and cropping structure. It is measured by the total amount of precipitation received in a year.
- (5) Annual average temperature (Tmp) is a fundamental climatic determinant of crop growth conditions and regional cropping patterns. It is measured by the mean temperature over a year.
- (6) Expenditure on regional agriculture, forestry and water affairs (Afw) may influence farmers' production incentives and land-use decisions. It is measured by its logarithm.
- (7) The level of agricultural industrialization (Ail) may shape cropping structure through its role in agricultural value chains. It is measured by the number of key leading national agricultural enterprises specializing in agriculture in the region.

4.2.4. Mechanism Variables

This paper selects the scale of agricultural labor force (ALF) and the level of agricultural socialized services (ASS) as mechanism variables. The rationale for choosing these two mechanisms lies in the fact that improvements in ANQPF significantly reduce the dependence of agricultural production on traditional labor, thereby leading to a contraction in the agricultural labor force. Since grain production is more easily standardized and mechanized, a reduction in labor imposes relatively limited constraints and may even facilitate the expansion of large-scale grain cultivation. In contrast, cash crops typically require more intensive manual management, and a tightening labor supply tends to constrain their expansion [11,12]. At the same time, the advancement of ANQPF promotes the development of agricultural socialized service systems, which are better aligned with the contiguous and standardized production characteristics of grain crops and can effectively reduce service costs in grain production, thereby enhancing their comparative advantage over cash crops. Therefore, through the dual channels of labor reallocation and service cost optimization, productivity improvement systematically reshapes the relative return structure between grain and cash crops, thereby suppressing NGPC [12–14].

With economic development and the expansion of productivity disparities among sectors, there is a continuous trend of agricultural labor force flowing from the agricultural sector to the non-agricultural sector. Relevant studies show that the number of people still employed in the primary industry in the agricultural sector and their proportion in the three industries can reflect the surplus scale and transfer potential of agricultural labor force [49]. Therefore, this paper measures the scale of agricultural labor force (ALF) using two approaches: the ratio of employment in the primary industry to total regional

employment (ALF1), and the logarithm of the number of people employed in the primary industry (ALF2).

Agricultural socialized services refer to a series of services provided by service organizations during the production process of farmers or agricultural business entities, including research and development, training, and technical guidance. The development of agricultural production services can be measured by the output value of agriculture, forestry, animal husbandry and fishery services per unit sown area [50,51]. Based on the reliability and availability of the data, and following existing literature on measuring the level of agricultural socialized services, this paper employs two indicators to capture the level of agricultural socialized services (ASS): the ratio of the output value for the agricultural, forestry, animal husbandry, and fishery service industry to the sown area of crops (ASS1), and the ratio of the output value for the same service industry to the sown area of grain (ASS2). The descriptive statistical analysis of the variables is shown in Table 2.

Table 2. Descriptive statistics.

Variable	Obs	Mean	SD	Min	Max	Median
NGPC	1265	36.561	12.034	4.029	71.333	36.677
ANQPF	1265	0.193	0.099	0.029	0.743	0.178
Urb	1265	0.543	0.131	0.234	0.896	0.526
Open	1265	4.642	1.98	0.039	10.649	4.649
Fdi	1265	11.145	1.988	3.009	16.022	11.156
Pre	1265	1.226	0.376	0.074	2.62	1.183
Tmp	1265	17.247	2.185	5.238	23.559	17.4
Afw	1265	3.851	0.63	1.789	6.262	3.905
Ail	1265	3.181	4.083	0	31	2
ALF1	1265	0.344	0.148	0.015	0.775	0.344
ALF2	1265	4.135	0.689	2.088	6.205	4.226
ASS1	1265	0.335	0.298	0.009	2.581	0.233
ASS2	1265	0.571	0.598	0.018	5.583	0.368

4.3. Empirical Models

4.3.1. Basic Regression Model

To capture the impact of ANQPF on the level of NGPC and to control the heterogeneity of individuals and time, the following two-way fixed-effects model was constructed:

$$NGPC_{it} = \beta_0 + \beta_1 ANQPF_{it} + X_{it}'\gamma + \mu_i + \lambda_t + \varepsilon_{it}, \quad (36)$$

where the subscripts i and t denote the prefecture-level city and the year, respectively. $NGPC_{it}$ represents the level of non-grain production of cultivated land in prefecture-level city i in year t . $ANQPF_{it}$ stands for the level of ANQPF in prefecture-level city i in year t . X_{it} is a vector comprising a series of control variables. γ is the vector of coefficients for the control variables. μ_i represents the individual fixed effect, used to control for individual heterogeneity that does not vary over time. λ_t denotes the time fixed effect, used to control for common shocks that vary over time but do not differ across individuals. ε_{it} is the random error term. β_1 is the core estimated coefficient, reflecting the net effect of ANQPF on the level of NGPC after controlling for individual characteristics, time trends and other factors.

4.3.2. Mechanism Verification Model

The traditional three-step mediation framework is widely used in empirical studies to identify potential transmission mechanisms. However, recent studies have also highlighted that this approach may suffer from potential endogeneity issues in estimating indirect

effects. When the influence of the mediating variable on the dependent variable is relatively clear, the core of mechanism testing lies in verifying the influence of the core explanatory variable on the mediating variable [52].

The theoretical framework developed in Section 3 provides a formal basis for the transmission mechanisms considered in this paper. As shown in Section 3.2, the impact of ANQPF operates through heterogeneous structural characteristics of cropping systems, leading to systematic adjustments in production behavior.

These theoretical results, derived from the structural decomposition in Section 3, are consistent with existing literature. Empirical studies have documented that agricultural labor allocation plays a crucial role in shaping crop structure decisions, particularly through the differential labor intensity between grain and cash crops. Grain crops are generally characterized by relatively lower labor intensity and higher mechanization compatibility, whereas cash crops tend to be more labor-intensive due to finer field management, more heterogeneous production tasks, and lower standardization. As a result, changes in agricultural labor availability and allocation tend to have asymmetric effects on grain and non-grain production systems, thereby influencing farmers' cropping decisions through heterogeneous labor constraints across crop types [12]. Similarly, land consolidation, scale expansion, and mechanization development have been shown to improve production efficiency and facilitate crop structure adjustment [38,39]. Furthermore, mechanization and digital agricultural technologies have been found to generate stronger productivity gains in grain production due to higher structural compatibility with standardized production systems [40]. In contrast, non-grain crops are characterized by heterogeneous production conditions, fragmented plots, and more complex agronomic operations, which increase coordination costs and reduce the efficiency gains from social service [12–14].

Accordingly, the task of mechanism testing lies in proving that ANQPF will significantly affect the scale of agricultural labor force and the level of agricultural socialized service. The mechanism verification model is constructed as follows:

$$ALF_{it} = \beta_0 + \beta_1 ANQPF_{it} + X_{it}'\gamma + \mu_i + \lambda_t + \varepsilon_{it} \quad (37)$$

$$ASS_{it} = \beta_0 + \beta_1 ANQPF_{it} + X_{it}'\gamma + \mu_i + \lambda_t + \varepsilon_{it} \quad (38)$$

where ALF_{it} denotes the scale of agricultural labor force in prefecture-level city i in year t , while ASS_{it} represents the level of agricultural socialized services in the same city and year.

4.3.3. Threshold Effect Model

There are significant stage differences and spatial differentiation characteristics in ANQPF and the level of NGPC. To conduct heterogeneity analysis based on the characteristics of the variables and examine whether the impact of ANQPF on the level of NGPC undergoes structural changes due to the threshold variable q_{it} being in different intervals, this paper refers to Hansen's threshold model construction method [53] and constructs the basic threshold effect model as follows:

$$NGPC_{it} = \beta_0 + \beta_1 ANQPF_{it} \times I(q_{it} \leq \theta) + \beta_2 ANQPF_{it} \times I(q_{it} > \theta) + X_{it}'\gamma + \varepsilon_{it} \quad (39)$$

where θ is the threshold value to be estimated and $I(\cdot)$ is the indicator function used to partition the sample interval.

4.3.4. Two-Stage Least Squares (2SLS) Model

A key concern in estimating the effect of ANQPF on NGPC is potential endogeneity arising from reverse causality and omitted variables. First, reverse causality may exist because changes in crop structure can, in turn, influence the development of ANQPF. For

instance, a shift from grain crops to non-grain crops may alter production scale, mechanization demand, and the adoption of digital and standardized agricultural technologies, thereby affecting the measured level of ANQPF at the regional level.

Second, both ANQPF and NGPC may be jointly determined by unobserved regional characteristics, such as natural resource endowments, market accessibility, and policy support. These factors can simultaneously promote the development of modern agricultural productive forces and influence farmers' crop allocation decisions, leading to omitted variable bias if not properly controlled.

To address these potential endogeneity concerns, this study adopts a two-stage least squares (2SLS) model. The baseline structural model is specified as:

$$\text{ANQPF}_{it} = \pi_0 + \pi_1 Z_{it} + X_{it}'\gamma + \mu_i + \lambda_t + \varepsilon_{it}, \quad (40)$$

where Z_{it} denotes the instrumental variable.

The second-stage regression replaces ANQPF_{it} with its fitted values:

$$\text{NGPC}_{it} = \beta_0 + \beta_1 \widehat{\text{ANQPF}}_{it} + X_{it}'\gamma + \mu_i + \lambda_t + \varepsilon_{it} \quad (41)$$

5. Empirical Results

5.1. Basic Regressions

To examine the direct impact of ANQPF on the level of NGPC, this paper constructs a two-way fixed-effects panel regression model based on Formula (36). To mitigate the possible interference that the introduction of control variables may cause to the core relationship and ensure the robustness of the results, this paper adopts the method of gradually adding control variables for estimation. The estimation results are shown in Table 3. From Column (1), only the core explanatory variable ANQPF is included. Control variables are introduced successively from Column (2) to (7), and all pre-defined control variables are included in Column (8).

The results show that the estimated coefficient of the core explanatory variable ANQPF is negative in all model Settings and is highly significant at the 1% statistical level. With the gradual introduction of various control variables, the coefficient estimates of ANQPF fluctuate between -22.030 and -24.444 , demonstrating good robustness. Taking the analysis results in Column (8) as an example, the coefficient of ANQPF is -24.444 (with a standard error of 8.608), which means that under the condition of keeping other factors unchanged, for every one-unit increase in the ANQPF in the region, the average ratio of NGPC in the region in the current year will decrease by approximately 24.444 percentage points. This result strongly supports the research hypothesis H1 of this paper. The improvement of ANQPF can indeed effectively curb NGPC.

5.2. Mechanism Tests

Basic regression results establish that ANQPF exerts a significant inhibitory effect on NGPC. To verify the specific transmission pathways based on the hypotheses in Section 3, this paper conducts a mechanism analysis, designating the scale of agricultural labor forces (ALF) and the level of agricultural socialized services (ASS) as the key mechanism variables. Table 4 reports the results of the mechanism test.

Columns (1) and (2) demonstrate the impact of ANQPF on the scale of ALF. ALF1 is measured by the ratio of employment in the primary industry to total regional employment, and ALF2 is measured by the logarithm of the number of people employed in the primary industry. The results show that regardless of which measurement method is used, the coefficient of ANQPF is significantly negative. The coefficient of ALF1 is -0.157 , which is significant at least at the 10% level. The coefficient of ALF2 is -1.031 , which is significant

at least at the 1% level. This finding validates the labor substitution path in the theoretical analysis. The development of ANQPF characterized by intelligent equipment and advanced technology has reduced the absolute reliance of agricultural production on agricultural labor by replacing traditional human labor and improving production efficiency, thus releasing labor from agricultural production. Objectively, this has led to the transfer of labor from the agricultural sector to the non-agricultural sector and provided favorable conditions for the allocation of cultivated land from labor-intensive cash crops to more scalable and mechanized grain crops.

Table 3. Results of the panel regression.

Variable	(1) NGPC	(2) NGPC	(3) NGPC	(4) NGPC	(5) NGPC	(6) NGPC	(7) NGPC	(8) NGPC
ANQPF	−23.527 *** (7.924)	−23.487 *** (8.038)	−23.293 *** (8.142)	−22.706 *** (8.142)	−22.551 *** (8.024)	−22.030 *** (8.044)	−23.532 *** (8.335)	−24.444 *** (8.608)
Urb		9.809 (9.876)	9.818 (9.843)	8.877 (9.924)	8.510 (9.931)	9.008 (9.845)	7.230 (9.390)	6.942 (9.326)
Open			−0.162 (0.621)	−0.135 (0.618)	−0.136 (0.615)	−0.103 (0.609)	−0.043 (0.610)	−0.029 (0.615)
Fdi				−0.214 (0.210)	−0.232 (0.211)	−0.246 (0.213)	−0.263 (0.205)	−0.265 (0.206)
Pre					1.756 *** (0.636)	1.632 ** (0.660)	1.583 ** (0.624)	1.564 ** (0.626)
Tmp						−0.287 * (0.159)	−0.325 ** (0.163)	−0.315 * (0.164)
Afw							−3.292 (2.311)	−3.280 (2.317)
Ail								0.175 (0.242)
_cons	38.044 *** (1.067)	33.345 *** (5.117)	34.006 *** (5.950)	36.722 *** (6.960)	35.253 *** (7.067)	40.003 *** (8.007)	53.112 *** (9.517)	52.707 *** (9.655)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1265	1265	1265	1265	1265	1265	1265	1265
adj.R ²	0.125	0.127	0.126	0.128	0.134	0.138	0.153	0.154

Note: Values in parentheses indicate robust standard errors for clustering at the city level, and *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively. The same rule applies to the tables that follow.

Table 4. Results of the mechanism tests.

Variable	(1) ALF1	(2) ALF2	(3) ASS1	(4) ASS2
ANQPF	−0.157 * (0.081)	−1.031 *** (0.324)	0.721 * (0.401)	1.788 * (1.049)
_cons	0.465 *** (0.133)	5.263 *** (0.558)	0.217 (0.361)	0.221 (0.890)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
N	1265	1265	1265	1265
adj. R ²	0.007	0.453	0.397	0.342

Note: Values in parentheses indicate robust standard errors for clustering at the city level, and *, *** indicate significance at the 10% and 1% levels, respectively.

Columns (3) and (4) illustrate the impact of ANQPF on the level of agricultural socialized services (ASS). Specifically, ASS1 is measured by the ratio of the output value of forestry, animal husbandry, and fishery services to the total crop sown area, while ASS2 scales this same service output value by the grain sown area. The results show that the coefficient of ASS1 is 0.721 and that of ASS2 is 1.788, both of which are significant at least at the 10% level. This result supports the cost path of socialized services in theoretical analysis. The development of ANQPF has not only fostered and expanded the market for agricultural socialized services, but, due to its technological research and application being markedly biased toward grain crops, has enabled these services to achieve greater economies of scale in grain production, thereby significantly reducing the unit cost of services for grain cultivation. The resulting cost advantage in grain production further incentivizes farmers to expand their grain planting.

The results of the mechanism test show that the ANQPF mainly changes the factor constraints and cost structure in agricultural production through two paths: reducing the reliance on agricultural labor force and enhancing agricultural socialized services. Eventually, it guides farmers' planting decisions to tilt towards grain production, thereby curbing the trend of NGPC. Hypotheses H2a and H2b are thus verified.

5.3. Endogeneity Tests

Although the panel regression and mechanism analysis provide preliminary support for our conclusions, the results may still be contaminated by endogeneity, specifically due to reverse causality and omitted variable bias. First, in regions with pronounced non-grain production trends, the local agricultural structure tends to be dominated by high-value cash crops. This economic shifting may steer local R&D, extension services, and socialized infrastructure toward non-grain sectors, thereby impeding the development of grain-oriented ANQPF and triggering reverse causality. Second, unobserved confounding factors omitted from the empirical specification could still bias our estimates. To mitigate these endogeneity concerns and ensure the robustness of our findings, this paper employs both the two-stage least squares (2SLS) and the generalized method of moments (GMM) approaches.

First, we employ the two-stage least squares (2SLS) method for estimation. To satisfy the relevance and exogeneity conditions of a valid instrument, and drawing on the relevant literature [54], this paper constructs an instrumental variable defined as the interaction term between the logarithm of the spherical distance from the sample city to Hangzhou and a year dummy variable. On the one hand, the development of ANQPF heavily depends on the diffusion of technology, the mobility of talent, and the transmission of information. As the capital of Zhejiang Province and an important science and innovation hub in the Yangtze River Delta, Hangzhou serves as both the origin and the diffusion center of agricultural technological innovation. Geographic distance acts as a natural barrier to technology diffusion. Therefore, this instrumental variable can effectively capture the spatial gradient of ANQPF diffusion and is strongly correlated with the level of ANQPF across cities. On the other hand, geographic distance, as a spatial characteristic of cities, does not have a direct relationship with the economic activities or outcomes of individual societies [55]. The spherical distance from a city to Hangzhou is historically determined and bears only a weak direct relationship to contemporaneous city-level cropping decisions. The interaction term between this distance and time captures a technology diffusion process driven by external sources, which can be basically regarded as exogenous to local agricultural conditions, thereby largely satisfying the exclusion restriction assumption. Columns (1) and (2) of Table 5 report the estimation results of IV-2SLS.

Table 5. Results of the endogeneity tests.

Method	IV-2SLS		GMM	
	First-Stage (1) IV-ANQPF	Second-Stage (2) NGPC	System GMM (3) NGPC	Difference GMM (4) NGPC
Dist × Year	−0.003 *** (0.001)			
IV-ANQPF		−192.284 *** (50.216)		
L.NGPC			0.977 *** (0.017)	0.544 *** (0.084)
ANQPF			−6.781 *** (2.508)	−11.361 * (6.219)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
_cons	48.870 (11.370)	87.742 (19.782)	−0.277 (1.874)	0.221 (0.249)
Kleibergen–Papp rk Wald F	18.398			
Kleibergen–Papp rk LM	17.911 ***			
Hansen test			0.334	0.205
Number of instruments			115	97
AR(1)			0.000	0.001
AR(2)			0.694	0.829
N	1265	1265	1150	1035

Note: Values in parentheses indicate robust standard errors for clustering at the city level, and *, ***, indicate significance at the 10% and 1% levels, respectively.

The first-stage regression coefficient is significantly negative at the 1% level, indicating that ANQPF levels are lower in cities farther from Hangzhou, which aligns with the classic law of geographic distance decay. After addressing endogeneity, the second-stage coefficient for ANQPF is −192.284 and remains significant at the 1% level. This confirms that ANQPF exerts a robust inhibitory effect on NGPC even after accounting for endogeneity. The estimated coefficient is approximately 7.87 times larger than the baseline regression result. According to the relevant literature [56], this coefficient reflects the difference between the local average treatment effect (LATE) and the average treatment effect (ATE), and thus falls within a reasonable range. Furthermore, the Kleibergen–Paap rk Wald F statistic exceeds the 10% critical value, and the Kleibergen–Paap rk LM statistic is significant at the 1% level. These diagnostics verify that the instrument successfully passes both the weak instrument and under-identification tests, demonstrating a strong correlation with the endogenous variable (ANQPF) and further consolidating the robustness of our findings.

In addition, since this study does not assume that the instrumental variables used in the 2SLS model are perfectly exogenous, we also employ the imperfect instrumental variable (IIV) approach for estimation. This method relaxes the strict exogeneity assumption of instrumental variables and replaces it with two weaker assumptions. First, the direction of correlation between the instrumental variable and the error term is assumed to be the same as that between the endogenous explanatory variable and the error term. Second, even if the instrumental variable is imperfect, its correlation with the error term is assumed to be weaker than that of the endogenous explanatory variable. Following the approach in the relevant literature [57,58], we compute the upper bound of the estimator under the extreme case of imperfect instruments. The estimated upper bound is −68.93, and the upper limit of its 10% confidence interval is −50.87. Both values are below zero, indicating that

although the instrumental variable may not be perfectly exogenous, it can still effectively identify the direction of the impact of ANQPF on NGPC.

Second, the estimation is conducted using the generalized method of moments (GMM). Considering that the cropping structure of cultivated land exhibits path dependence and involves certain adjustment costs, the lagged level of NGPC may directly affect current planting decisions. To control for this dynamic effect and address the endogeneity arising from lagged explanatory variables, we construct a dynamic panel model that includes the one-period lag of the dependent variable. Columns (3) and (4) in Table 5 report the estimation results using System GMM and Difference GMM, respectively. In both estimation methods, the coefficient of the lagged NGPC is significantly positive, confirming the persistence of the non-grain production trend. After controlling for this dynamic effect, the coefficient of the core explanatory variable ANQPF is significantly negative at the 1% level under System GMM and at the 10% level under Difference GMM, corroborating the robustness of the baseline regression results. Moreover, the model passes the Arellano-Bond test for serial correlation, with AR(1) being significant and AR(2) insignificant, indicating no second-order autocorrelation in the first-differenced residuals. The Hansen test for overidentifying restrictions yields a p -value greater than 0.1, further supporting the validity of the instrumental variable specification.

5.4. Robustness Tests

To ensure the validity of our findings, this paper undertakes a series of robustness checks employing multiple methodologies. Specifically, we evaluate the results using the following six approaches below.

- (1) Replacing the explanatory variables and re-synthesizing the ANQPF index using the principal component analysis method indicates that the conclusion of the panel regression is not limited to a single measurement method of ANQPF.
- (2) Eliminate special samples. Considering the particularities of provincial capital cities and municipalities directly under the Central Government in terms of politics, economy, and resource allocation, their agricultural development models, policy implementation intensities, and decisions on cultivated land utilization may have systematic differences from those of other cities. Therefore, this paper excludes all provincial capital cities and municipalities directly under the Central Government from the entire sample, retains only ordinary prefecture-level cities as sub-samples, and re-estimates them.
- (3) All continuous variables are winsorized at the 1% and 99% levels to mitigate the influence of extreme values, which could otherwise disproportionately affect the estimation results and lead to biased inferences. This step ensures that the analysis reflects the central tendency of the data and provides more stable coefficient estimates.
- (4) The bootstrap resampling method is employed to compute more robust standard errors, allowing for more reliable statistical inference by accounting for potential sampling variability and non-normality in the error terms. This approach enhances the credibility of the estimated effects, particularly in the presence of complex or high-dimensional data structures.
- (5) The explanatory variable is lagged by one period to mitigate potential simultaneity bias, ensuring that the observed relationships are less likely to be confounded by reverse causality. By introducing temporal separation between the dependent and independent variables, the analysis can more accurately capture the causal influence of ANQPF on NGPC.

- (6) The double machine learning (DML) approach is employed to address potential model misspecification in traditional parametric models and to more effectively control for confounding factors in high-dimensional settings.

The regression results are shown in Tables 6 and 7.

Table 6. Results of the robustness tests.

Variable	(1) NGPC	(2) NGPC	(3) NGPC	(4) NGPC	(5) NGPC
ANQPF	−1.851 *** (0.630)	−37.931 *** (9.865)	−29.056 *** (8.409)	−24.444 *** (4.956)	−26.816 *** (7.282)
_cons	48.180 *** (9.119)	55.348 *** (8.973)	54.465 *** (9.089)	52.707 *** (6.409)	58.135 *** (8.929)
Controls	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
N	1265	1155	1265	1265	1150
adj. R ²	0.148	0.166	0.158	0.154	0.172

Note: Values in parentheses indicate robust standard errors for clustering at the city level, and *** indicates significance at the 1% level.

Table 7. Results of double machine learning.

Variable	(1) Lasso cv NGPC	(2) Nnet NGPC	(3) Linsvm NGPC
ANQPF	−21.413 ** (8.631)	−7.765 ** (3.729)	−12.436 * (6.649)
_cons	0.000 (0.032)	0.084 (0.24)	0.398 (0.538)
Controls	Yes	Yes	Yes
N	1265	1265	1265

Note: Values in parentheses indicate robust standard errors for clustering at the city level, and *, ** indicate significance at the 10% and 5% levels, respectively.

Columns (1) to (5) of Table 6 report the test results using the first five robustness tests. The results show that the coefficient of the core explanatory variable ANQPF has always remained negative at a significance level of at least 5%. Table 7 reports the double machine learning results obtained using three machine learning algorithms. The cross-validated LASSO regression, neural network, and linear support vector machine are respectively used for dual machine learning. Among them, the first two algorithms remain negative at a significance level of 5%, and the third algorithm remains negative at a significance level of 10%. The above robustness test results strongly prove the robustness of the panel regression.

6. Extended Analysis

6.1. Heterogeneity Analysis Based on Double Perspectives

Panel regression revealed the average inhibitory effect of ANQPF on the level of NGPC. However, both the development of ANQPF and the pattern of cultivated land utilization in China show significant policy differentiation and development-stage heterogeneity. Accordingly, this section examines heterogeneity from two dimensions. The first is the policy dimension, focusing on Regional policy designation, namely whether a city belongs to a major grain-producing area. The second is the economic dimension, which is described from two aspects: per capita GDP and the urban–rural income gap.

6.1.1. Heterogeneity Analysis Based on Regional Policy Designation

First, to examine regional policy heterogeneity, we partition the sample into major and non-major grain-producing regions. Columns (1) and (2) of Table 8 present the corresponding subsample regression estimates.

Table 8. Results of the heterogeneity analysis.

Variable	Grain Producing Policy			Economic Development		
	Major Grain-Producing Regions	Non-Major Grain-Producing Regions	Low per Capita GDP	High per Capita GDP	Low Urban–Rural Income Gap	High Urban–Rural Income Gap
	(1) NGPC	(2) NGPC	(3) NGPC	(4) NGPC	(5) NGPC	(6) NGPC
ANQPF	−25.450 ** (11.327)	−5.975 (9.001)	−47.050 *** (15.374)	−2.856 (7.957)	−11.605 (11.804)	−29.352 *** (9.811)
_cons	53.315 *** (11.983)	41.234 *** (10.570)	64.361 *** (11.201)	50.930 *** (16.988)	32.775 ** (15.734)	63.251 *** (10.783)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
N	968	297	638	627	638	627
adj. R ²	0.109	0.443	0.296	0.046	0.066	0.253

Note: Values in parentheses indicate robust standard errors for clustering at the city level, and **, *** indicate significance at the 5%, and 1% levels, respectively.

The results show that the inhibitory effect of ANQPF on NGPC is significantly negative in major grain-producing regions, but not significant in non-major grain-producing regions. It indicates that the major grain-producing regions shoulder the strategic core function of ensuring national food security. Their farmland protection policy system is more rigorous, and the foundation for the scale and specialization of grain production is also better. Therefore, the introduction of ANQPF is more likely to be integrated into the existing production system and stabilize the sown area of grain more effectively. In non-major grain-producing regions, the multi-functionality of agriculture is stronger, the market orientation of cultivated land utilization is more obvious, and the impact of ANQPF may be diluted or reshaped by complex non-grain-oriented driving factors. This grouping demonstrates that the functional positioning of the country's major grain-producing region has strengthened the enabling effect of ANQPF.

6.1.2. Heterogeneity Analysis Based on Economic Development Level

Secondly, the sample is divided into two groups according to the median per capita GDP in each year, namely low per capita GDP and high per capita GDP. Columns (3) and (4) of Table 8 present the results of the grouped regression. The test finds that the inhibitory effect of ANQPF is significantly negative in areas with low per capita GDP, but not significant in areas with high per capita GDP. This proves that the stabilizing grain production effect of the ANQPF is systematically related to the economic development stage of the region. In regions with low per capita GDP, agriculture accounts for a relatively large share of the economy and labor costs are relatively low, while capital and technology are scarce. In such contexts, the marginal contribution of ANQPF may be particularly significant, substantially altering the cost–benefit ratio of traditional production and thereby strongly influencing farmers' decision-making. In regions with high per capita GDP, non-agricultural employment opportunities are abundant, but the opportunity cost of agricultural labor is high. NGPC is often intertwined with diverse forces such as urbanization and ecological return to farmland. The technological progress of agricultural production itself may struggle to counter the strong non-agricultural pull.

Finally, the sample is divided into two groups based on the median urban–rural income gap in each year, namely low and high urban–rural income gaps. Columns (5) and (6) of Table 8 present the results of the group-wise regressions. The test found that the inhibitory effect of ANQPF was significantly negative in areas with a high urban–rural income gap, but not significant in areas with a low urban–rural gap. This result proves that ANQPF has special value in alleviating the vulnerability of agricultural production caused by the imbalance between urban and rural development. The income gap between urban and rural areas can reflect the development momentum of rural areas and the retention status of the labor force. Regions with a high income gap usually face more severe net outflow pressure of agricultural labor force. The labor substitution attribute of ANQPF can play a more crucial compensatory role in such regions, stabilizing production by alleviating labor force constraints. In regions where the income gap between urban and rural areas is low, rural development is relatively balanced and the pressure of labor outflow is small. The role of ANQPF may be more reflected in improving quality and efficiency rather than making up for labor shortages, and it has other special values.

Taken together, per capita GDP and the urban–rural income gap jointly reflect different but related dimensions of regional economic development, capturing both the overall level of economic advancement and the internal distributional structure of income. Therefore, they provide complementary perspectives for a more comprehensive understanding of how ANQPF affects NGPC across different economic contexts.

6.2. Nonlinear Relationship Testing Based on Quadratic Term Models

While heterogeneity analysis indicates that the mitigating effect of ANQPF on NGPC is non-uniform and dependent on macro-level conditions, it implies that the performance of its transmission channels may also evolve with the level of ANQPF. To examine whether such evolution exhibits nonlinear characteristics, we introduce a quadratic term of ANQPF into the baseline model, with results reported in Table 9.

This section adopts a method of gradually adding control variables for estimation. Column (1) includes only ANQPF and its squared term, while Columns (2)–(7) sequentially add control variables, and Column (8) reports the full specification. Across all models, both the linear and quadratic terms of ANQPF remain statistically significant. In the preferred specification (Column 8), the linear term is significantly negative at the 1% level, while the squared term is positive and marginally significant.

These results indicate that the effect of ANQPF on NGPC is nonlinear but remains monotonic within the observed sample range. Specifically, ANQPF continues to suppress NGPC, but the magnitude of this suppressing effect weakens as ANQPF increases, indicating diminishing marginal returns. In other words, the grain-stabilizing effect is stronger at earlier stages of ANQPF improvement, but its incremental contribution gradually declines at higher levels of ANQPF.

Overall, this pattern implies that the effectiveness of ANQPF is stage-dependent and subject to diminishing marginal returns within the observed data range, suggesting that policy design should account for differences in the maturity level of agricultural productivity when promoting grain production stability.

6.3. Threshold Effect Test Based on Economic Development Level

The quadratic regression results suggest that the inhibitory effect of ANQPF on NGPC exhibits diminishing marginal returns as agricultural productivity increases. Building on this finding, a natural question is whether the effect varies systematically across different stages of economic development.

Table 9. Results of the quadratic term regression.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variable	NGPC	NGPC	NGPC	NGPC	NGPC	NGPC	NGPC	NGPC
ANQPF	−47.682 *** (15.670)	−50.534 *** (15.708)	−50.106 *** (16.222)	−49.888 *** (16.159)	−49.713 *** (16.063)	−49.394 *** (16.033)	−49.213 *** (15.924)	−49.147 *** (15.952)
ANQPF ²	29.906 * (15.405)	33.498 ** (15.816)	33.127 ** (16.150)	33.603 ** (16.132)	33.579 ** (16.001)	33.834 ** (15.933)	31.783 * (16.225)	30.731 * (16.354)
Urb		11.740 (9.559)	11.725 (9.564)	10.784 (9.642)	10.416 (9.652)	10.933 (9.553)	9.067 (9.030)	8.758 (8.959)
Open			−0.107 (0.624)	−0.078 (0.621)	−0.080 (0.618)	−0.046 (0.613)	0.010 (0.613)	0.020 (0.617)
Fdi				−0.221 (0.210)	−0.239 (0.211)	−0.252 (0.213)	−0.268 (0.206)	−0.270 (0.206)
Pre					1.755 *** (0.635)	1.631 ** (0.660)	1.582 ** (0.624)	1.565 ** (0.627)
Tmp						−0.289 * (0.159)	−0.327 ** (0.163)	−0.318 * (0.164)
Afw							−3.238 (2.298)	−3.229 (2.304)
Ail								0.150 (0.240)
_cons	40.581 *** (1.889)	35.261 *** (5.000)	35.677 *** (5.788)	38.497 *** (6.843)	37.028 *** (6.938)	41.828 *** (7.881)	54.612 *** (9.504)	54.213 *** (9.659)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1265	1265	1265	1265	1265	1265	1265	1265
adj. R ²	0.128	0.130	0.130	0.131	0.138	0.142	0.157	0.157

Note: Values in parentheses indicate robust standard errors for clustering at the city level, and *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Given that the heterogeneity analysis has already shown stronger effects in regions with lower per capita GDP, this section further examines whether there exists an economic development threshold that characterizes this variation more precisely. To this end, we employ a panel threshold regression model, using the logarithm of per capita GDP as the threshold variable.

To ensure the robustness of the threshold estimation results, this study adopts two different sample pruning ratios to control the potential influence of extreme values. The significance results of the threshold effect are shown in Table 10, and the threshold effects reflected by the LR likelihood ratio statistics are shown in Figures 1 and 2.

Table 10. Results of the threshold effect test.

Threshold Type	Trimming Ratio	Number of Bootstrap Replications	F-Value	<i>p</i> -Value	Critical Value		
					10%	5%	1%
First threshold	0.01	300	40.6	0.033 **	33.552	38.774	50.971
Second threshold			10.844	0.553	24.129	30.082	45.814
First threshold	0.05		41.604	0.017 **	30.424	37.737	42.513
Second threshold			8.996	0.583	22.808	26.38	37.244

Note: ** indicates significance at the 5% level.

Econometric diagnostics reveal that regardless of the trimming ratio, the single-threshold models are statistically significant at the 5% level, while the double-threshold models remain insignificant. These findings verify the existence of a single per capita GDP threshold in the relationship between ANQPF and NGPC. Driven by this single threshold, the sample observations are stratified into a low-economic-development regime and a high-

economic-development regime for independent estimations, with the regression outputs documented in Table 11.

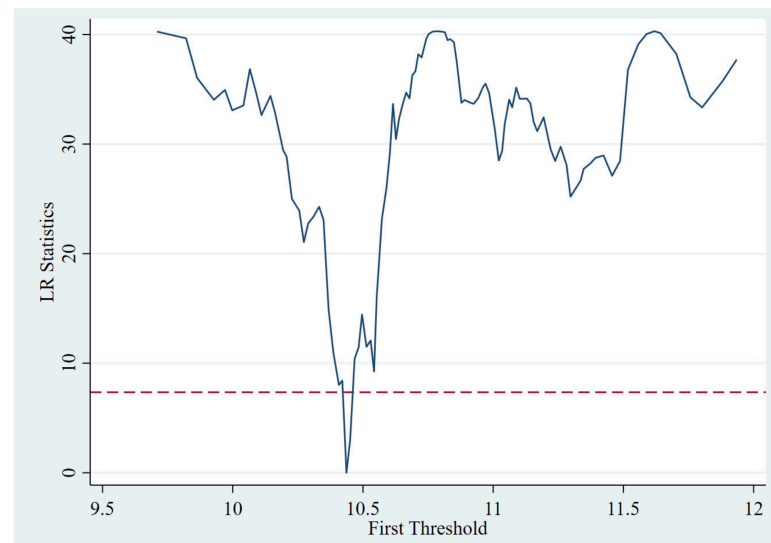


Figure 1. The single-threshold effect reflected in the LR likelihood ratio statistic when trim = 0.01.

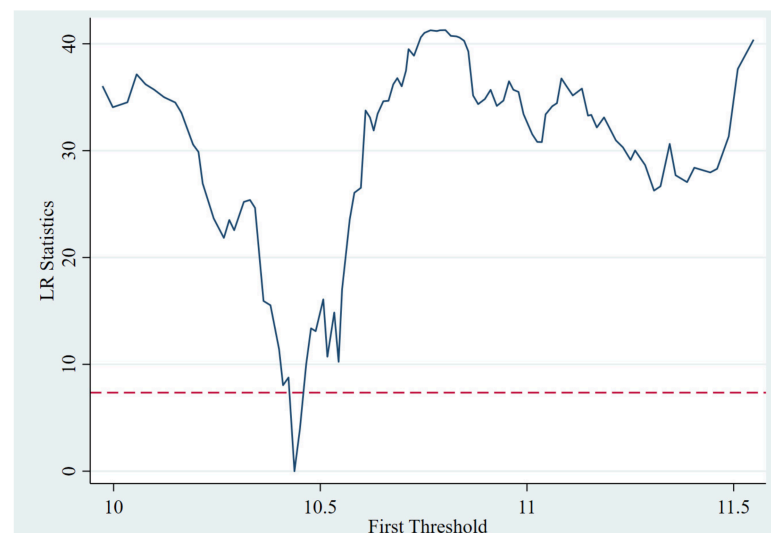


Figure 2. The single-threshold effect reflected in the LR likelihood ratio statistic when trim = 0.05.

Across both trimming percentages, the estimated threshold values are highly consistent, with their confidence intervals overlapping substantially, thereby confirming the robustness of the threshold estimation. The empirical results indicate that in the regime where per capita GDP remains below the threshold, the coefficient of ANQPF is significantly negative (at the 5% and 1% levels, respectively). This demonstrates that ANQPF's capacity to curb NGPC is exceptionally potent during earlier stages of economic development. However, once a region's economic development surpasses this threshold, although the coefficient remains negative, its magnitude shrinks considerably and loses statistical significance.

This pattern underscores the context-dependent efficacy of ANQPF. Specifically, the panel threshold analysis yields a single per capita GDP threshold of roughly 34,000 CNY (or 10.437 in logarithmic form), located just below the midpoint of the full-sample economic distribution. Given that the economic development level across a substantial share of the sample has already crossed this threshold, the pronounced NGPC-mitigating effect of

ANQPF manifests primarily in late-developing and economically constrained regions that have yet to reach this tipping point.

Table 11. Results of the threshold regression.

Variable	(1) Trim = 0.01 NGPC	(2) Trim = 0.05 NGPC
ANQPF $\times$ I ($q_{it} \leq \gamma$)	−25.986 ** (9.967)	−25.716 *** (9.803)
ANQPF $\times$ I ($q_{it} > \gamma$)	−7.416 (6.710)	−7.266 (6.706)
_cons	34.565 *** (5.702)	34.584 *** (5.680)
Controls	Yes	Yes
N	1265	1265
adj. R ²	0.138	0.138
Threshold	10.437	10.438
95% confidence interval	[10.421, 10.451]	[10.423, 10.451]

Note: Values in parentheses indicate robust standard errors for clustering at the city level, and **, *** indicate significance at the 5%, and 1% levels, respectively.

Clearly, policies aimed at promoting the development of ANQPF to ensure food security should be prioritized, with particular focus on regions with relatively low levels of economic development. In these areas, the marginal returns on technological investment are highest, producing immediate effects in stabilizing grain-sown areas. In contrast, in regions where economic development has surpassed the threshold, the influence of ANQPF on farmers' planting decisions has gradually diminished. Addressing the more complex challenges of cultivated land use in such regions requires a more comprehensive policy framework, integrating technological empowerment with industrial integration, ecological compensation, and other diversified tools. Only through such a multifaceted approach can the rising trend of non-grain production of cultivated land be effectively managed.

7. Conclusions and Policy Implications

This paper constructs a dual-path theoretical model based on labor substitution and cost reduction through socialized services and empirically examines it using panel data from 115 prefecture-level cities in the Yangtze River Basin, China, during 2013–2023. It systematically investigates the mechanisms and boundary conditions through which ANQPF influences the trend of NGPC. The main findings are as follows.

First, improvements in ANQPF significantly suppress the level of NGPC. The core mechanism lies in substituting traditional labor through technological advancement and developing a socialized service system that favors grain crops. This systematically reduces the relative cost and labor constraints of grain production and reshapes farmers' planting decisions.

Second, this inhibitory effect exhibits significant heterogeneity and nonlinearity. The grain-stabilizing effect of ANQPF is particularly pronounced in major grain-producing regions, areas with lower economic development, and regions with higher urban–rural income gaps, while it tends to weaken in highly developed areas. Further analysis reveals that the grain-stabilizing effect of ANQPF undergoes structural attenuation once regional economic development surpasses a specific threshold. Furthermore, the enhancement of ANQPF is subject to diminishing marginal returns; relying exclusively on technological iteration inevitably faces a “ceiling effect”, suggesting that innovation alone cannot permanently sustain long-term grain stability.

The findings provide important policy implications. Although initial improvements in ANQPF in relevant regions can indeed contribute to grain stabilization, the existence of threshold effects and nonlinear relationships indicates that agricultural development and food security policies should not be confined to mere technological promotion. Instead, they should be tailored according to regional development stages and characteristics, forming a differentiated, coordinated, and precise governance framework.

First, in major grain-producing regions and economically less developed areas, policies should adhere to a core strategy of technology empowerment and enhancement. These regions exhibit the highest marginal returns regarding the grain-stabilizing efficacy of ANQPF. Consequently, sustained investment in smart agricultural machinery, premium seed varieties, and digital infrastructure is essential. Furthermore, establishing comprehensive socialized service systems that encompass the entire production cycle is critical to driving down costs and enhancing efficiency, thereby incentivizing grain cultivation and fortifying national food security.

Second, in regions with higher economic development and advanced levels of ANQPF, the policy logic requires fundamental adjustment. In these areas, the grain-stabilizing effect of technological development has diminished, and high land opportunity costs alongside diversified industrial returns have become important drivers of non-grain production. Therefore, policy focus must shift from reliance on technology alone toward a composite governance system that guarantees farmers' income from grain cultivation. In these regions, governments should strictly enforce land-use regulations while prioritizing the establishment of high-standard grain production ecological compensation mechanisms commensurate with local fiscal capacity. Through financial compensation for grain, the relative profitability gap of grain cultivation can be directly addressed, enabling technological functions to evolve from factor substitution toward value chain enhancement. Governments must guide ANQPF investments toward deep processing of grains, brand agriculture, and smart supply chain development to increase the added value of the entire grain industry, thereby restoring economic competitiveness of grain cultivation in high-end markets.

Third, different regions should assume differentiated regional responsibilities. Governments should encourage areas with higher economic development and ANQPF levels to leverage their capital and technological advantages to take on front- and back-end functions, including agricultural core technology R&D, seed source breakthroughs, and emergency supply system development. This approach can continuously enhance the grain value chain and establish a coordinated pattern of "R&D in coastal areas, production capacity in inland regions" in conjunction with major grain-producing areas.

In summary, the key to curbing NGPC and ensuring food security lies in stabilizing farmers' income. As technology advances and ANQPF rises, governments should recognize the conditionality and stage-specific nature of its effectiveness. By designing differentiated and coordinated policies, technological progress and institutional innovation can act synergistically, effectively addressing the challenges of cultivated land protection at different stages of regional development.

8. Future Prospects and International Discussions

Despite providing robust empirical evidence on the relationship between ANQPF and NGPC, several limitations should be acknowledged. First, although the empirical analysis is based on prefecture-level panel data from the Yangtze River Basin in China, which ensures strong regional representativeness and internal comparability, the findings may not be directly generalizable to other countries or regions with different agricultural structures, institutional environments, and stages of agricultural development. Second, while the ANQPF index constructed in this study provides a systematic and multidimensional

measure of agricultural productivity transformation, capturing the coordinated evolution of agricultural labor, production materials, and production conditions, it remains a composite indicator. Its main strength lies in its holistic representation of structural upgrading. However, as a synthesized index, it may still have limited capacity to fully capture the most frontier and rapidly emerging dimensions of “new” productive forces, particularly those related to digital agriculture, platform-based organizational forms, and intelligent agricultural technologies that are currently evolving and increasingly shaping agricultural production restructuring, but are not yet fully and precisely reflected in existing statistical measurement systems. Third, although this study identifies the main transmission channels through labor substitution and agricultural socialized services within a unified theoretical framework, farmers’ actual decision-making processes remain highly complex, and other unobserved behavioral factors may also contribute to cropping structure adjustments.

Future research can be further extended in line with the above limitations. First, cross-country comparative studies could be conducted to examine whether the relationship between ANQPF and non-grain production holds across different institutional environments and stages of agricultural development, thereby improving the external validity and broader applicability of the findings. Second, the measurement framework of ANQPF could be further refined by incorporating more frontier dimensions of agricultural transformation, such as digital platform penetration, smart agriculture applications, and AI-enabled production systems, so as to better capture the evolving nature of agricultural productivity upgrading while preserving its current strength in reflecting the integrated transformation of labor, means of production, and production conditions. Third, future studies could further incorporate the complexity of farmers’ decision-making behavior by considering richer behavioral dimensions, such as heterogeneous risk preferences, market participation, and expectation formation mechanisms, to provide a more comprehensive understanding of how ANQPF shapes cropping structure decisions.

In addition to the above discussions on limitations and future research, it is also useful to place the findings of this study within a broader international context. In China, the relationship between ANQPF and NGPC reflects a structural transformation process driven by labor-saving technological progress and the development of agricultural socialized services. This mechanism is consistent with the general pattern of agricultural modernization, in which productivity improvements reshape relative factor costs and thereby influence crop allocation decisions. In developed economies such as the United States and the European Union, agricultural production has already undergone a long process of mechanization, large-scale operation, and service outsourcing. As a result, the structural constraints of labor and service costs are relatively weak, and cropping patterns tend to be more stable over time. In this sense, the mechanism identified in this study can be interpreted as an extension of earlier stages of agricultural modernization observed in advanced economies. By contrast, in many developing economies, where agriculture is still characterized by fragmented landholdings, higher labor dependence, and less developed service markets, the transmission of productivity improvements into structural cropping adjustments may be less pronounced or more heterogeneous. Institutional constraints and factor market imperfections may also shape the extent to which technological progress translates into changes in crop allocation. Overall, these comparisons suggest that the findings of this study not only reflect China’s ongoing agricultural transformation, but also provide a useful reference for understanding how agricultural productivity upgrading may influence land-use decisions across different stages of development.

Author Contributions: Conceptualization, Z.Q. and Y.W. (Yue Wang); methodology, Z.Q. and Y.W. (Yue Wang); software, Z.Q.; validation, X.L., S.L. and S.W.; formal analysis, S.L., S.W. and Y.W. (Yuanjie Wang); investigation, X.L.; data curation, Z.Q., X.L. and S.W.; writing—original draft preparation, Z.Q.; writing—review and editing, Y.W. (Yue Wang); visualization, X.L.; supervision, Y.W. (Yue Wang); project administration, Y.W. (Yue Wang); funding acquisition, Y.W. (Yue Wang) and Z.Q. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Social Science Fund of China (grant numbers: 24XJY033), the National College Students Innovation and Entrepreneurship Training Program (grant number: 202510626012), and Sichuan Science and Technology Program (grant number: 2026YFHZ0282).

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The original contributions presented in the study are included in the article, and further inquiries can be directed to the corresponding author.

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

Abbreviations

The following abbreviations are used in this manuscript:

ANQPF	Agricultural new quality productive forces
NGPC	Non-grain production of cultivated land
ALF	Agricultural labor force
ASS	Agricultural socialized services

References

1. Zhu, Y.; Wang, Z.; Zhu, X. New reflections on food security and land use strategies based on the evolution of Chinese dietary patterns. *Land Use Policy* **2023**, *126*, 106520. [\[CrossRef\]](#)
2. Cui, K.; Shoemaker, S.P. A look at food security in China. *npj Sci. Food* **2018**, *2*, 4. [\[CrossRef\]](#) [\[PubMed\]](#)
3. Chen, F.; Liu, J.; Chang, Y.; Zhang, Q.; Yu, H.; Zhang, S. Spatial pattern differentiation of non-grain cultivated land and its driving factors in China. *China Land Sci.* **2021**, *35*, 33–43. [\[CrossRef\]](#)
4. Meng, F.; Tan, Y.; Chen, H.; Xiong, W. Spatial-temporal evolution patterns and influencing factors of “non-grain” utilization of cultivated land in China. *China Land Sci.* **2022**, *36*, 97–106. [\[CrossRef\]](#)
5. Su, Y.; Qian, K.; Lin, L.; Wang, K.; Guan, T.; Gan, M. Identifying the driving forces of non-grain production expansion in rural China and its implications for policies on cultivated land protection. *Land Use Policy* **2020**, *92*, 104435. [\[CrossRef\]](#)
6. Pan, W.; Wang, J.; Lu, Z.; Liu, Y.; Li, Y. High-quality development in China: Measurement system, spatial pattern, and improvement paths. *Habitat Int.* **2021**, *118*, 102458. [\[CrossRef\]](#)
7. Li, W.; Li, L.; Li, W.; Sheng, C.; Li, X. The impact of the integration of digital and real economies on agricultural new quality productive forces: Empirical evidence from China’s major grain-producing areas. *Agriculture* **2026**, *16*, 141. [\[CrossRef\]](#)
8. Huang, Q.; Guo, W.; Wang, Y. A study of the impact of new quality productive forces on agricultural modernization: Empirical evidence from China. *Agriculture* **2024**, *14*, 1935. [\[CrossRef\]](#)
9. Chang, J.; Liu, X. Spatial correlation network structure of agricultural new quality productive forces and their impact on urban–rural integration in the Ji-shaped bend cities of the Yellow River, China. *J. Rural Stud.* **2026**, *124*, 103987. [\[CrossRef\]](#)
10. You, L.; Tian, X.Y. New quality agricultural productive force: Realistic logic, connotation analysis and generation mechanism. *Econ. Probl.* **2024**, *6*, 27–35. [\[CrossRef\]](#)
11. Rivera-Padilla, A. Crop choice, trade costs, and agricultural productivity. *J. Dev. Econ.* **2020**, *146*, 102517. [\[CrossRef\]](#)
12. Qiu, T.; Luo, B. An analysis of the non-grainization effect of developing new-type agricultural business entities. *J. Renmin Univ. China* **2025**, *39*, 59–74.
13. Li, R.; Chen, J.; Xu, D. The impact of agricultural socialized service on grain production: Evidence from rural China. *Agriculture* **2024**, *14*, 785. [\[CrossRef\]](#)
14. Liao, L.; Guo, J.; Peng, Y.; Liu, Y.; Ling, Y.; Tang, Y. Agricultural socialized services and grain yield per unit area: Empirical evidence from Jiangxi Province, China. *Front. Sustain. Food Syst.* **2025**, *9*, 1611236. [\[CrossRef\]](#)
15. Luo, B.; Geng, P. New quality agricultural productivity: Theoretical framework, core concepts, and enhancement pathways. *Issues Agric. Econ.* **2024**, *4*, 13–26. [\[CrossRef\]](#)

16. Huang, J.K. New quality productive forces in agriculture: Connotation and denotation, potential and challenges, and development ideas. *China Rural Surv.* **2024**, *45*, 19–34. [[CrossRef](#)]
17. Zhu, D.; Ye, L. Agricultural new quality productive force in China: Level measurement and dynamic evolution. *Stat. Decis.* **2024**, *40*, 24–30. [[CrossRef](#)]
18. Wang, L.; Fu, X.; Jiang, H.; Yang, J. Development level measurement, regional differences and coupling coordination of agricultural new quality productivity. *J. Agro-For. Econ. Manag.* **2025**, *24*, 55–64. [[CrossRef](#)]
19. Zeng, F.; Chen, H. Impact of digital finance on agricultural new quality productive forces at the provincial level. *Econ. Geogr.* **2025**, *45*, 200–209. [[CrossRef](#)]
20. Lin, L.; Gu, T.; Shi, Y. The influence of new quality productive forces on high-quality agricultural development in China: Mechanisms and empirical testing. *Agriculture* **2024**, *14*, 1022. [[CrossRef](#)]
21. Sun, Y.; Chang, Y.; Liu, J.; Ge, X.; Chen, F. Spatial differentiation of non-grain production on cultivated land and its driving factors in coastal China. *Sustainability* **2021**, *13*, 13064. [[CrossRef](#)]
22. Wang, J.; Dai, C. Identifying the spatial-temporal pattern of cropland's non-grain production and its effects on food security in China. *Foods* **2022**, *11*, 3494. [[CrossRef](#)] [[PubMed](#)]
23. Lu, D.; Wang, Z.; Su, K.; Zhou, Y.; Li, X.; Lin, A. Understanding the impact of cultivated land-use changes on China's grain production potential and policy implications: A perspective of non-agriculturalization, non-grainization, and marginalization. *J. Clean. Prod.* **2024**, *436*, 140647. [[CrossRef](#)]
24. Su, Y.; Li, C.; Wang, K.; Deng, J.; Shahtahmassebi, A.R.; Zhang, L.; Ao, W.; Guan, T.; Pan, Y.; Gan, M. Quantifying the spatiotemporal dynamics and multi-aspect performance of non-grain production during 2000–2015 at a fine scale. *Ecol. Indic.* **2019**, *101*, 410–419. [[CrossRef](#)]
25. Wang, X.; Song, X.; Wang, Y.; Xu, H.; Ma, Z. Understanding the distribution patterns and underlying mechanisms of non-grain use of cultivated land in rural China. *J. Rural Stud.* **2024**, *106*, 103223. [[CrossRef](#)]
26. Yang, Q.; Zhang, D. The influence of agricultural industrial policy on non-grain production of cultivated land: A case study of the “one village, one product” strategy implemented in the Guanzhong Plain of China. *Land Use Policy* **2021**, *108*, 105579. [[CrossRef](#)]
27. Wu, Y.; Yuan, C.; Liu, Z.; Wu, H.; Wei, X. Decoupling relationship between the non-grain production and intensification of cultivated land in China based on Tapio decoupling model. *J. Clean. Prod.* **2023**, *424*, 138800. [[CrossRef](#)]
28. Li, Q.; Chen, W.; Shi, H.; Zhang, S. Assessing the environmental impact of agricultural production structure transformation—Evidence from the non-grain production of cropland in China. *Environ. Impact Assess. Rev.* **2024**, *106*, 107489. [[CrossRef](#)]
29. Qiu, T.; Choy, S.B.; Li, S.; He, Q.; Luo, B. Does land renting-in reduce grain production? Evidence from rural China. *Land Use Policy* **2020**, *90*, 104311. [[CrossRef](#)]
30. Shen, W.; Hu, Q.; Zhang, Z. Impacts of in situ urbanisation on grain production: Evidence from the Yangtze River Delta, China. *Habitat Int.* **2024**, *143*, 102989. [[CrossRef](#)]
31. Fu, Y.; Zhu, Y. Internet use and technical efficiency of grain production in China: A bias-corrected stochastic frontier model. *Humanit. Soc. Sci. Commun.* **2023**, *10*, 643. [[CrossRef](#)]
32. Min, S.; Paudel, K.P. Mechanization and efficiency in rice production in China. *J. Integr. Agric.* **2021**, *20*, 1996–2008. [[CrossRef](#)]
33. Shi, X.; Zhou, F.; van Riper, C.; He, W.; Li, X.; Zhang, F.; Wang, T.; Cheng, C.; Zhou, Q.; Huang, Z.; et al. Ensuring China's food security in a geographical shift of its grain production: Driving factors, threats, and solutions. *Resour. Conserv. Recycl.* **2024**, *210*, 107845. [[CrossRef](#)]
34. Zhang, S.; Li, B.; Yang, Y. Efficiency analysis of scientific and technological innovation in grain production based on improved grey incidence analysis. *Agriculture* **2021**, *11*, 1241. [[CrossRef](#)]
35. Luo, B.; Qiu, T. Adjustment of China's agricultural planting structure: “Non-grain orientation” or “grain orientation”. *Soc. Sci. Front.* **2018**, *2*, 39–51.
36. Yang, X.; Shi, H. Specialization and product diversity. *Am. Econ. Rev.* **1992**, *82*, 392–398.
37. Shi, H.; Yang, X. A new theory of industrialization. *J. Comp. Econ.* **1995**, *20*, 171–189. [[CrossRef](#)]
38. Li, Y.; He, J.; Zheng, J.; Xu, D. How can continuous land transfers guarantee food security? A study from the perspectives of plot size. *Appl. Econ.* **2025**, *57*, 4426–4440. [[CrossRef](#)]
39. Li, P.; Li, R.; Xu, D. The impact of operating-plot-continuous scale management on “non-grainization”: Empirical evidence from Sichuan Province, China. *J. Rural Stud.* **2026**, *124*, 104178. [[CrossRef](#)]
40. Qiao, F. The impact of mechanization on crop production in China. *Appl. Econ.* **2023**, *55*, 1728–1741. [[CrossRef](#)]
41. Zhang, G.; Yang, Z. Agricultural New Quality Productive Forces, Agricultural Socialized Services and Food Security. *Contemp. Econ. Res.* **2025**, *2*, 68–78.
42. Zhang, D.; Yang, W.; Kang, D.; Zhang, H. Spatial-temporal characteristics and policy implication for non-grain production of cultivated land in Guanzhong Region. *Land Use Policy* **2023**, *125*, 106466. [[CrossRef](#)]

43. Hou, S. AI-driven Transformation of new-quality productive forces: Theoretical framework and financial empowerment pathways. *Financ. Res. Lett.* **2025**, *86*, 108804. [[CrossRef](#)]
44. Liu, Y.; Gong, X.; Wang, B. Big data technology and new quality productive forces: Evidence from national big data comprehensive pilot zones in China. *Int. Rev. Econ. Financ.* **2026**, *109*, 105458. [[CrossRef](#)]
45. Xiong, Y.; Lei, C.; Huang, X.; Fan, Y.; Xu, Y. How do agricultural new quality productive forces promote high-quality agricultural development? Evidence from the Tuojiang River Basin, China. *Agriculture* **2026**, *16*, 1186. [[CrossRef](#)]
46. Li, G.; Li, M. Provincial-Level New Quality Productive Forces in China: Evaluation, Spatial Pattern and Evolution Characteristics. *Econ. Geogr.* **2024**, *44*, 116–125. [[CrossRef](#)]
47. Zhang, J.; Li, H.; Li, H. The impact of digital–green synergy on agricultural new quality productive forces in China. *Agriculture* **2025**, *15*, 2403. [[CrossRef](#)]
48. Xu, Y.; Zhang, Y.; Wang, S.; Zhao, M.; Li, G.; Kang, Y.; Zhao, C. Internal mechanism and empirical analysis of digital economy's impact on agricultural new quality productive forces: Evidence from China. *Sustainability* **2025**, *17*, 6844. [[CrossRef](#)]
49. Shi, C.; Zhang, Y. Land certification and rural labor migration in China: Evidence from provincial panel data. *Resour. Sci.* **2022**, *44*, 647–659. [[CrossRef](#)]
50. Yu, Y.; Chi, Z.; Yu, Y.; Zhao, J.; Peng, L. Boosting agricultural green development: Does socialized service matter? *PLoS ONE* **2024**, *19*, e0306055. [[CrossRef](#)] [[PubMed](#)]
51. Zhang, H.; Guo, X. The promotion effect of agricultural producer services on agricultural total factor productivity: Regional differences and spatial effect. *J. Agrotech. Econ.* **2021**, *5*, 93–107. [[CrossRef](#)]
52. Jiang, T. Mediating effects and moderating effects in causal inference. *China Ind. Econ.* **2022**, *5*, 100–120. [[CrossRef](#)]
53. Hansen, B.E. Threshold effects in non-dynamic panels: Estimation, testing, and inference. *J. Econom.* **1999**, *93*, 345–368. [[CrossRef](#)]
54. Peng, Y.; Zhou, H.; Su, L. Does the participation in digital economy improve farmers' social class identity? Empirical evidence from Ningxia, Chongqing, and Sichuan provinces. *Chin. Rural Econ.* **2022**, *10*, 59–81.
55. Chen, Y. Logic, imagination and interpretation: The application of instrumental variables for causal inference in the social sciences. *Sociol. Stud.* **2012**, *6*, 192–216. [[CrossRef](#)]
56. Jiang, W. Have instrumental variables brought us closer to the truth? *Rev. Corp. Financ. Stud.* **2017**, *6*, 127–140. [[CrossRef](#)]
57. Nevo, A.; Rosen, A.M. Identification with imperfect instruments. *Rev. Econ. Stat.* **2012**, *94*, 659–671. [[CrossRef](#)]
58. Yuan, C.; Li, Y.; Li, Z.; Meng, Q. The governance effects of independent director training: Evidence from earnings management. *J. World Econ.* **2026**, *49*, 167–198. [[CrossRef](#)]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.