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Essay

How Does Environmental Regulation Affect the Development of China's Pig Industry

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Abstract: (1) Background: The pig production sector is a cornerstone in China's agricultural industry and it urgently needs a transition from a conventional sector to one that is efficient, sustainable, and of high quality. (2) Methods: This study examines the effects of environmental regulation (ER) on the development of the pig industry (DPI) between 2005 and 2019. From the perspective of the breeding, production, and consumption industry chain, a comprehensive evaluation index system is used to assess the progress of the pig industry. Furthermore, the effects of ER on the DPI and its mechanism were evaluated using the FGLS and system-GMM. (3) Results: According to the empirical findings, ER exhibits a U-shaped non-linear effect on DPI in both high- and low-pig-production zones. Technological innovation and large-scale farming would lessen the detrimental effects of ER on DPI. Additionally, according to the outcomes of the implementation of local environmental protection policies, LER and DPI have an inverted U-shaped relationship in major producing areas and a U-shaped relationship in non-major producing areas. (4) Conclusions: This essay offers several solutions and advice, including strengthening environmental regulation legislation and encouraging breeding industry advancements.

Keywords: environmental regulation; high-quality development; pig industry; Chinese provinces; industrial chain; technological innovation; large-scale breeding

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1. Introduction

Sustainable development is the "golden key" to resolving today's global issues, achieving a balance between the environment, society, and economics. However, in the hog-feeding supply chain, accomplishing this goal is more challenging. According to data made public by the American Farm Bureau database, in 2021, pork consumption was 3.1 times greater than the global per capita level in China, and over half of the world's pork is supplied there. China has long been the largest global producer and eater of pork as a result. Nevertheless, hog manure from excessive pig production and consumption is associated with the risks of poor air quality and contaminated water supplies [1]. According to the Food and Agriculture Organization of the United Nations (FAO), carbon emissions contribute 5% of the total global emissions [2]. Organic compounds in pig manure are the main culprits in water eutrophication [3]. The communique of the second national pollution source census published by China in 2020 shows that in 2017, the total pollutant loads generated from livestock and poultry were 1000.53 million tons of chemical oxygen demand, 110,900 tons of ammonia nitrogen, 596,300 tons of total nitrogen, and 119,700 tons of total phosphorus (Data from https://www.mee.gov.cn/gkml/hbb/bgg/201002/t20100210_185698.htm (accessed on 13 December 2022)), topping the list of agricultural pollution sources. Widespread rural household scatter breeding is one of the prime causes of livestock pollution [4], compared with North America and Europe, which have a high proportion of large-scale farms. Even China recently established several regulations to increase the proportion of large-scale farming to achieve industrial transformation and upgrading, with the percentage of large-scale farming rising from 36.6% in 2011 to 57.1% in 2020 (Data from http://www.moa.gov.cn/ (accessed on 14 December 2022)). The sustainable growth of China's pig industry continues to have far to go because of the characteristics of low-scale efficiency, the low automation level, poor capital formation, high labor intensity, and high carbon emissions [5].

China will steadfastly adhere to the road of high-quality growth with an ecological priority, as well as green and low-carbon development, to completely implement the new development concept. In September 2020, the central government released its Opinions on Promoting the High-Quality Development of the Animal Husbandry Industry. It stated that it would speed up the development of contemporary livestock and poultry breeding, animal epidemic prevention, processing, and circulation systems; boost the industry's quality, efficiency, and competitiveness; and establish a new pattern of high-quality development oriented toward green development. According to studies, there are two main paths to green transformation: enterprise-independent technology innovation and government-led environmental regulation [6], and the latter aids in overcoming "market failures" [7]. Simultaneously, environmental policy can promote sustainable innovation and help achieve the objective of green transformation [8]. The Chinese government has implemented several "green agreements" in the context of the ecological pollution-driven transformation of the livestock industry (Table 1), including increasing pollution control inputs, establishing emission standards and associated penalties, and stepping up pollution oversight. From the standpoint of environmental protection, pollution associated with livestock and poultry breeding has greatly decreased, but the rate of pig farming has gradually increased. The new objective of China's pig industry is synergistic development, which includes economic growth, resource use, supply stability, environmental protection, livestock and poultry health, quality, and safety.

Table 1. Part of the policy of livestock and poultry environmental.

Year	Document
2005	Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Waste
2005	Law of the People's Republic of China on Animal Husbandry
2008	Water Pollution Prevention and Control Law of the People's Republic of China
2008	Opinions on promoting the sustainable and healthy development of animal husbandry
2011	Livestock breeding industry pollution prevention and control technology policy
2013	Regulations on Prevention and Control of Pollution from Livestock and Poultry Farming on a Large Scale
2014	Opinions on the establishment of harmless treatment mechanisms for sick and dead livestock and poultry
2015	Law of the People's Republic of China on Animal Husbandry
2015	Southern Water Network Area Hog Breeding Layout Adjustment Optimization Guidance
2016	Technical guide for the delineation of livestock and poultry breeding no-keep areas
2016	Environmental Protection Tax Law of the People's Republic of China
2017	Opinions of the General Office of the State Council on accelerating the resource utilization of livestock and poultry breeding waste
2017	Issuance of the Regulations on the Implementation of the Environmental Protection Tax Law of the People's Republic of China
2018	Opinions on the in-depth promotion of ecological, environmental protection
2018	Agricultural and rural pollution control action plan
2019	Opinions on strengthening the prevention and control of African swine fever
2019	Notice on further standardizing the regulations and management of livestock breeding no-keep areas to promote the development of pig production

When investigating the impact of environmental regulations on the development of the pig industry, it is required to study the government's possible arbitrary regulation strategy based on the short-term goal of suppressing the "pig cycle" and the overall impact of the new behavioral characteristics of breeding subjects under environmental regulations on the industrial chain. First of all, local governments are motivated to make arbitrary decisions when implementing environmental regulatory standards, which may lead to the deterioration of environmental pollution in the "reverse pig cycle" [9]. Due to the possible conflict of policy objectives in different pig cycle stages, local governments are hesitant to implement regulation policies. On the one hand, to achieve the emission reduction goals, local governments need to actively respond to the environmental regulation policies issued by the central government; on the other, In 1998, China's Ministry of Agriculture proposed the construction of the "Vegetable Basket Project" to solve the problem of food market supply shortages. The local government has the responsibility to ensure supply and price stability as pigs are part of the basket. As a result, local governments tend to choose between environmental regulation and pig supply. Secondly, the specific effect and realization method of environmental regulation driving industrial chain transformation and upgrading needs to be further clarified. The compliance cost effect and innovation offset effect are the two categories used to categorize the formation mechanisms of environmental regulation effects in the literature [10]. The expense of pollution control will rise because of environmental regulation, and businesses will scale down production to maintain profits or force businesses to make green innovations to compensate for environmental management costs, thus improving green productivity [11]. It is necessary to systematically study the dynamic impacts, heterogeneity, and impact mechanisms of environmental regulation on the whole pig industry chain for the process of scale transformation in the context of dual carbon targets.

We used data from China from 2005 to 2019 to analyze the effects of ER on DPI to close this research gap. The following aspects show how the donations were accomplished. First and foremost, this is the first attempt to gauge the pig industry's development level from the standpoint of the industrial chain, which includes feed, medical care, breeding, slaughter, consumption, etc. Secondly, the dynamic panel model is utilized to analyze the impacts and variety of ER on the DPI, taking into account the dynamic sustainability of the DPI. Thirdly, it is crucial to explore whether technological innovation and large-scale breeding form the innovation offset effect in the process of pig industry transformation. Finally, the amount of local environmental regulations is utilized to further assess how provincial governments will implement national environmental regulations.

The remainder of the essay is organized as follows: Section 2 provides a literature review, followed by theoretical analysis and the research hypothesis in Section 3, and the building of the model and indicators in Section 4. While Section 5 analyzes the empirical findings, Section 6 offers the conclusion and policy consequences.

2. Literature Review

2.1. Study on the Evaluation of the Development of the Pig Industry

Scholars have researched the development of industries such as manufacturing [12], agriculture [13,14], and the tourism industry [15]. There are two mainstream measurement methods: The first one takes total factor productivity (TFP), which can better reflect the efficiency and structure of economic growth but fails to show the sustainability of green development. Subsequently, Liu et al. [16] calculated green total factor productivity (GTFP) by incorporating environmental factors based on TFP to reflect the comprehensive competitiveness of the regional economy. The second method is to construct a comprehensive development index covering social progress, ecological benefit, and economic growth from a multi-dimensional perspective. In addition, research on the development of the pig industry primarily starts from specific factors, including pig production, price, layout, large-scale breeding, green development, pollution emissions [17,18], etc. These studies are mainly about "how to ensure supply" and "reduce environmental pollution". As the live pig industry has a long industrial chain, great demand for people's livelihood, and wide coverage, the pig industry's overall growth cannot be determined by a single measure. Pig welfare cannot be disregarded as a component of the pig industry's sustainable development. Therefore, this paper will comprehensively evaluate the development of the pig industry in different producing areas from the perspective of the industrial chain.

2.2. Influence of ER on Industrial Development

Some of the literature has prospectively emphasized the effect of environmental regulation on a specific dimension of industrial development, including the effect of environmental regulation on industrial productivity [19], competitiveness [20], economic growth [21], technological progress [22,23], green development [24], employment [25,26], etc. Meanwhile, scholars have also conducted a rich discussion on the connection between environmental regulations and industrial development, resulting in the following three most prominent points of view. The first is the compliance cost theory, which contends that the compliance expense will prevent enterprise innovation spending and lower total factor productivity due to the increasing cost of pollution control brought on by environmental constraints [27]. The next is the theory of innovation compensation. Porter's hypothesis is a crucial example of this idea. According to Porter, pollution is a symptom of economic waste, and effective environmental rules can spur innovation and produce win-win outcomes by partially or entirely offsetting the cost of pollution prevention [28]. Following this, scholars have divided the Porter hypothesis into "strong" and "weak", where "strong" denotes that the innovation compensation effect may entirely offset compliance costs, and "weak" denotes that it can only partially do so [29]. A non-linear relationship characterizes the third [30]. That is, environmental regulations and the expansion of green production are correlated in an inverted U-shaped non-linear relationship. Environmental control significantly influences the rise in green productivity when it falls below a certain threshold. When it crosses a certain threshold, environmental control will lead to a fall in the growth of green productivity [31]. The diverse policy alternatives, study domains, and research viewpoints are the main contributors to the disparity between research findings.

2.3. Influence of ER on the Pig Industry

The focus of a previous study, the interaction between environmental restrictions and the pig industry, is mostly shown in location choice, spatial clustering, yield reduction, and the enhancement of ecological efficiency. The geography of livestock farms can be significantly affected by changes in environmental regulation intensity [32,33]; a liberal regulatory regime may attract livestock producers to establish facilities in these localities [34], to avoid additional pollution costs [35]. As agglomeration economies, improved feeding technology, lower feed prices, and lower transportation costs drive the trend toward bigger and more spatially concentrated livestock operations [36]. Even the fuzzy effect of the pig manure management system in environmental regulation does not hinder the spatial agglomeration of pig production but increases the role of spatial spillover in the agglomeration process [37]. Herath et al. [34] and Pan et al. [38] discovered that variations in the severity of environmental restrictions had an impact on the quantity of hog sector inventories, and local environmental policies led to lower livestock production in regulated areas. Meanwhile, environmental protection displays clear benefits in the pig industry. For instance, environmental regulation encourages pig farmers to embrace green technology [39], enhancing the ecological effectiveness and total green total factor productivity of pig breeding [40].

2.4. Empirical Review

Although there are numerous pieces of research on the effect of environmental legislation on industrial development, these studies have the following flaws: First, there is a lack of evaluation of the development of the pig industry from the perspective of the industrial chain. In addition to pig production capacity, animal welfare, environmental protection, and material supply are all part of the sustainable development of the pig industry. Secondly, studies on the consequences of environmental legislation tend to be very micro-focused, excluding the variations and interactions that occur throughout the industrial chain. Third, environmental legislation in different regions is not properly taken into account. Local governments may have varying environmental policy intensities in different places because there are significant disparities in the spatial distribution of pig production due to variations, so the heterogeneity of impact effects needs to be further explored. Fourth, the internal law and specific mechanism of environmental regulation affecting the development of the live pig industry with multiple objectives have not been clarified. Finally, the degree to which central and local governments implement environmental regulations is uncertain since the GDP orientation of local governments under a system of political competition results in the lax implementation of environmental policies. Based on this, it is necessary to discuss the impact of environmental regulation on the pig industry and its mechanism from the perspective of industrial chain development.

3. Theoretical Analysis and Research Hypothesis

Environmental regulations are laws created and put into effect to address the negative externalities that environmental pollution has on the economy and society [41]. There are two opposing viewpoints in the academic community on the policy impact of environmental regulation: "cost-effectiveness" and the "innovation compensation effect." Some academicians emphasize the "compliance cost hypothesis" concerning "cost-effectiveness" to highlight how the enforcement of environmental legislation will raise the expenditures of businesses and other micro-entities and also stifle innovation and technological advancement [42,43]. The second is the "innovation compensation effect", which is supported by academicians who believe that reasonable environmental restrictions might encourage businesses to advance their technology and so increase productivity and competitiveness [44,45]. As a result, this paper develops a framework for the theoretical analysis (see Figure 1) and suggests a research hypothesis.

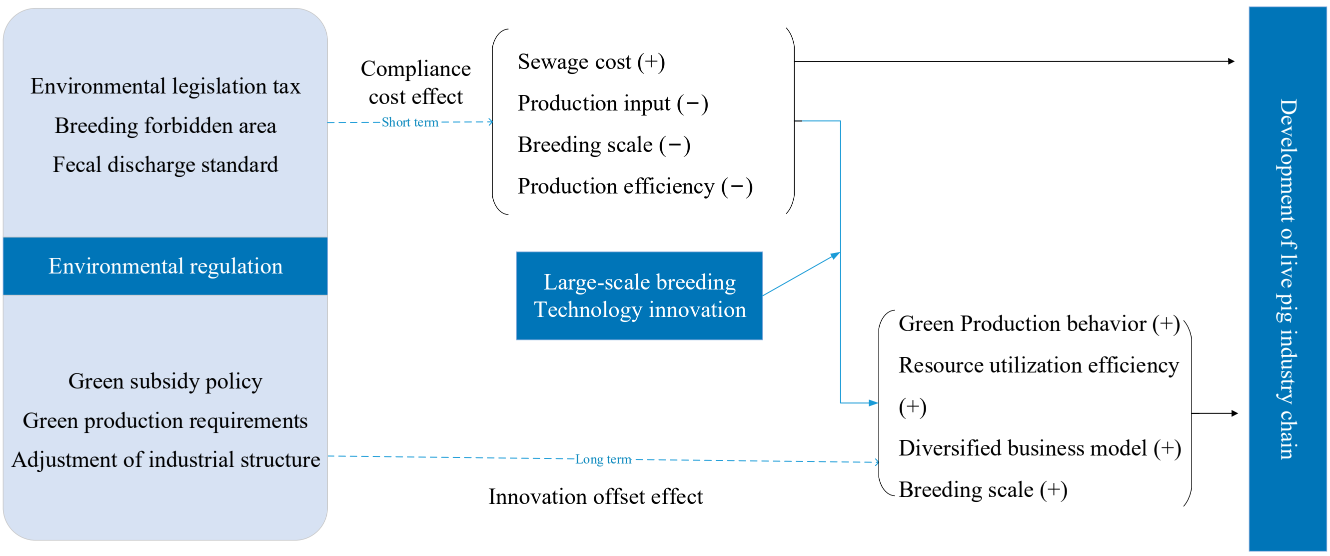

Figure 1. The influence path. Note: "(+)" means increase and "(−)" means decrease.

From the short-term perspective, environmental regulations support the "follow the cost hypothesis". First and foremost, the taxation of environmental legislation will raise the expenses of production for businesses and farmers, thus decreasing the profitability of pig-participating entities and lowering the enthusiasm of pig farmers [20]. Moreover, the division of prohibited areas for pig farming directly restricts enterprises' and farmers' breeding areas and forces them to withdraw from breeding and transfer breeding sites [46]. Finally, the cost of upgrading pollution control equipment, sewage technology applications, and system maintenance will go up as a result of emission reduction and pollution control laws. Pollution control spending's "crowding out" effects on investment in R&D will temporarily take place, and financial limitations will prevent businesses and farmers from using their productive inputs, further reducing production efficiency [47]. Environmental regulatory pressure from the environmental protection department on the primary pig farming body will weaken farmers' trust in production in the short term, affecting the pig industry's upstream and downstream development. Excessive economic penalties will drive farmers to seek compensation from pig welfare, such as reduced feed quality, medical services, and so on. The above will run counter to the original intention of environmental protection regulations and is not advantageous for the sustained growth of the pig business. As a result, the following theories are proposed in this paper:

Hypothesis 1. *In the short term, environmental regulations will reduce the development of the hog industry chain through cost-effective and crowding-out effects.*

From a long-term perspective, environmental regulation forms the "innovation compensation effect" [48]. First, long-term supervision will progressively alter producers' expectations for policy and knowledge of the environment [7] and improve pollution control technology and equipment input. Secondly, due to the adverse impact of environmental regulations on corporate profitability, companies are forced to alter their business strategies and expand upstream and downstream into the production of veterinary medicines, piglet breeding, slaughtering and processing, distribution, and consumption to reduce transaction costs, as well as look for economies of scale. Finally, the subsidy policy reduces the dilemma of long-term financing constraints, stabilizes the confidence of businesses in green production, expands green credit, and eases the dilemma of pollutant emission investment, crowding out green R&D investment. In a nutshell, the compensatory impact of innovation will be gradually boosted by green technological innovation, investment in anti-pollution infrastructure, and public knowledge of environmental issues [49].

Hypothesis 2. *In the long run, environmental regulation will improve the development of the hog industry chain through the innovation compensation effect.*

The market selection mechanism will gradually eliminate the low-efficiency, high-pollution, and low-standard aquaculture retail and enterprises because of the implementation of environmental regulations. As a direct consequence, capital will flow to the capital-intensive or knowledge-intensive aquaculture enterprises, forming a new type of large-scale transformation and upgrading. The "reversed transmission" green technology innovation used by scale management companies as a response to environmental stress generates more than just "compensatory income" from blowdown costs [50]. Businesses that adopt green innovations into their production processes are far less reliant on the initial polluting manufacturing mode and can profit from economies of scale [40].

Hypothesis 3. *Large-scale farming and technological innovations play a positive moderating role between environmental regulation and the development of the pig industry chain.*

There is no doubt that the considerable differences in resource endowment, technological level, traffic conditions, market, technology, and policy shape the regional development pattern of the hog business [51]. The eastern and southern areas of China hold the majority of the country's pork production capability. Specifically, the southwest region is the mainstay of the pig farming hub due to the area's ideal environmental conditions, inexpensive labor, and low feed transportation costs. The southwest also supplies pork to coastal provinces while maintaining self-sufficiency [52]. To ensure the supply of hogs, the government in the southwest will therefore loosen its environmental regulations. The northwest, with its large zones, substantial land resources, as well as agricultural and by-product resources, is the origin of cattle and sheep breeding. The cost impact of environmental regulation on pig breeding is minimal because the primary targets of environmental regulation are cattle and sheep. The eastern coastal area is primarily a consuming region with limited production resources, developed transportation, and mass population agglomeration [5].

As a result, the governments in the eastern region frequently create regulatory measures with the protection of the environment as their main goal. Overall, the development of the hog business is generally impacted differently by the disparities in environmental legislation in each region. When environmental regulations are not as strict, businesses or farmers are more ready to pay the cost of pollution management than to develop innovative production and pollution control technology. As the level of environmental regulation rises, the profit from technical innovation grows more than pollution control. In conclusion, hypothesis 4 is developed.

Hypothesis 4. *There is regional heterogeneity in the impact of ER on the DPI.*

4. Method and Data

4.1. Method and Identification Strategies

4.1.1. Measure Method of DPI

The entropy weight method (EWM) is widely applied in a variety of areas, such as project assessment [53], quality evaluation [54], and project whole-life value evaluation [55]. To better fit the field of comprehensive quality of the pig industry with distinct links, fine seed breeding, feed production, pig health, pig breeding, resource utilization, slaughter and processing, and consumption were selected to evaluate the pig industry from upstream, middle, and downstream perspectives. A thorough analysis was conducted using the EWM, and the DPI's overall score was computed using the index weights [56]. These were the steps for calculation:

Supposing there are n evaluation objects and m evaluation indexes, these constitute the judgment matrix $X = (x_{ij})m * n$. where x_{ij} denotes the rating of the *j-th* index value of the i province.

Afterward, all indices are standardized. For the indicator, the larger the value, the better:

$$Q_{ij} = \frac{x_{ij} - \underset{i=1,2,\ldots n}{min} x_{ij}}{\underset{i=1,2,\ldots n}{max} x_{ij} - \underset{i=1,2,\ldots n}{min} x_{ij}} \tag{1}$$

By contrast, the smaller the value of the negative index, the better:

$$Q_{ij} = \frac{\underset{i=1,2,\ldots n}{max} x_{ij} - x_{ij}}{\underset{i=1,2,\ldots n}{max} x_{ij} - \underset{i=1,2,\ldots n}{min} x_{ij}} \tag{2}$$

where Q_{ij} is the normalized value and max x_{ij} and min x_{ij} are the maximum and minimum values of the corresponding indexes. In the next part, Q_{ij} is normalised to obtain the weight of each index P_{ij}, and the calculation of the information entropy E_j is shown:

$$E_j = -\frac{1}{\ln n}\sum_{i=1}^{n} P_{ij} ln(P_{ij}),\ \text{and}\ P_{ij} = Q_{ij} / \sum_{i=1}^{n} Q_{ij} \tag{3}$$

The indicator's entropy weight ω_j is calculated as follows:

$$\omega_j = \frac{1 - E_j}{m - \sum\limits_{j=1}^{m} E_j}, 0 \le \omega_j \le 1,\ \sum_{j=1}^{m} \omega_j = 1 \tag{4}$$

Finally, the score of the i province:

$$L_i = \sum_{j=1}^{m} (\omega_j Q_{ij}) \tag{5}$$

4.1.2. Identification Strategies

A benchmark was employed to comprehend how environmental regulation (ER) has affected the development of the pig industry (DPI) and was shown as follows:

$$DPI_{i,t} = \alpha_i + \beta_1 ER_{i,t} + \beta_2 PP_{i,t} + \beta_{22} PP_{i,t-1} + \phi Control_{i,t} + u_t + \varepsilon_{i,t} \quad (6)$$

where i and t refer to province and year, respectively, and $DPI_{i,t}$ indicates the comprehensive index of development quality of the pig industry. Considering the critical influence of pig price on both pig production and consumption [57], where the price has a lag on hog production [58], model (6) includes the current year pig price ($PP_{i,t}$) and its lag term ($PP_{i,t-1}$); $ER_{i,t}$ represents the intensity of environmental regulation of province i in year t; and $Control_{i,t}$ stands for the other control variables. We used education (EDU), industrial structure (IS), urbanization rate (UR), fixed assets investment (FAI), and infrastructure construction (IC) as control variables. α_i and u_t measure the individual and time effects, respectively, while $\varepsilon_{i,t}$ is the random error.

The theory states that ER may positively or negatively impact DPI. To study the non-linear properties between environmental regulation and the development index, this article introduced a quadratic term of environmental regulation with a logarithmic form. To eliminate heteroscedasticity, a logarithmic form was adopted:

$$DPI_{i,t} = \alpha_i + \beta_1 \ln ER_{i,t} + \beta_{12} \ln ER_{i,t}{}^2 + \beta_2 \ln PP_{i,t} + \beta_{22} \ln PP_{i,t-1} + \phi \ln Control_{i,t} + u_t + \varepsilon_{i,t} \quad (7)$$

When $\beta_{12} > 0$, *ER* and *DPI* have a U-shaped connection; otherwise, an inverted U-shaped relationship results.

The level of industry development is easily influenced by the accumulation of previous development. The index of the DPI is measured by synthesized indicators, which may lead to endogenous problems. To address the problem of endogeneity thanks to cumulative effects, the dynamic panel model is widely used [59].

$$\begin{aligned} DPI_{i,t} = \alpha_i \quad & + \beta_0 DPI_{i,t-1} + \beta_1 \ln ER_{i,t} + \beta_{12} \ln ER_{i,t}{}^2 + \beta_2 \ln PP_{i,t} + \beta_{22} \ln PP_{i,t-1} \\ & + \phi \ln Control_{i,t} + u_t + \varepsilon_{i,t} \end{aligned} \quad (8)$$

Therefore, first-order lagged variables of DPI were also included in the model. The estimation provided by the FGLS model is seen as being more reliable than the FE model as it avoids potential heteroscedasticity and sequence correlations. The SYS-GMM model can address the issue of data endogeneity [60]. In addition, according to Bond [61], the fixed-effect (FE) estimation method often underestimates the lag term coefficient of the explained variable, while the OLS estimation method overestimates it. In conclusion, if the lag term coefficient produced by applying the GMM estimation method is between FE and OLS, the chosen GMM estimation method is suitable, and both FE and OLS estimation were employed in this research.

Heterogeneity Analysis

According to research hypothesis 4, the layout of hogs in China exhibits geographical disparities due to differences in factor endowments and the environmental regulation effects in the corresponding regions may also differ. As a result, we grouped China's 30 provinces into major-, middle-, and low-production areas in the order of high to low average pig output. Group regression was used to examine how environmental rules affected the growth of the hog sector in various locations.

Analysis of Moderating Effect

According to Hypothesis 3, the effect of ER on DPI depends heavily on technological innovation and breeding scale. To further verify this hypothesis, we added the interaction terms of two moderating variables based on the original model, and tested the moderating effect. The model constructed was:

$$DPI_{i,t} = \alpha_i + \beta_0 DPI_{i,t-1} + \beta_1 \ln ER_{i,t} + \beta_{12} \ln ER_{i,t}{}^2 + \beta_2 \ln PP_{i,t} + \beta_{22} \ln PP_{i,t-1} + \beta_3 \ln ER_{i,t} \times \ln TI_{i,t} + \beta_{32} \ln TI_{i,t} + \phi \ln Control_{i,t} + u_t + \varepsilon_{i,t} \quad (9)$$

$$DPI_{i,t} = \alpha_i + \beta_0 DPI_{i,t-1} + \beta_1 \ln ER_{i,t} + \beta_{12} \ln ER_{i,t}{}^2 + \beta_2 \ln PP_{i,t} + \beta_{22} \ln PP_{i,t-1} + \beta_4 \ln ER_{i,t} \times \ln SF_{i,t} + \beta_{42} \ln SF_{i,t} + \phi \ln Control_{i,t} + u_t + \varepsilon_{i,t} \quad (10)$$

In the above formulae, the moderating variables include technological innovation (TI) and large-scale farming (LSF). At present, the existing research results mainly focus on the following two aspects to measure technological innovation: one is measured by R&D investment [30]. The other is measured by the number of patent licenses [11]. Since the data on agricultural R&D investment in each region of China are not available, TI is represented by the number of agricultural invention patent licenses. This information is from the State Intellectual Property Office, and its Patent Classification number pertains to the agriculture subsection of the Green Patent List. The proportion of large-scale farming (LSF) was measured by dividing the number of farmers with more than 500 head pigs by the total number of pig farmers.

4.2. Variable Specification

4.2.1. Dependent Variables

The DPI focuses on the growth of breeding volume and covers product production, processing, environment, and epidemic prevention. The synergistic development between multiple links of the chain constitutes the DPI. 18 quantifiable secondary indicators were determined from the upstream, midstream, and downstream based on perspectives of the industry chain to build a quality development evaluation system for the hog industry chain (Table 2).

Table 2. Weight of indicators.

First-Level Indicator	Secondary Indicator (Unit)	Index Attribute	Weight
Seed-breeding A	Number of breeding farms A1	+	0.0653
	Breeding sow stock (10,000 head) A2	+	0.0789
Feed production B	Pig feed output (ten thousand tons) B3	+	0.1112
	Output value of pig feed (10,000 yuan) B4	+	0.0919
Pig health C	Number of veterinary stations (10,000 head/station) C5	−	0.0422
	Veterinary technology (%) C6	+	0.0776
Production systems D	Number of slaughtered fattened hogs (10,000 head) D7	+	0.0283
	Pig market growth rate (%) D8	+	0.0553
	Labor productivity (%) D9	+	0.0323
	Scale farming (%) D10	+	0.1334
	Mechanical breeding capacity (KW/head) D11	+	0.0650
Resource utilization E	Contribution rate of nitrogen (%) E16	−	0.0331
	Contribution rate of phosphorus (%) E17	−	0.0195
	Contribution rate of potassium (%) E18	−	0.0193
Slaughter and processing F	Meat enterprise output (tons/piece) F12	+	0.0419
Product consumption G	Meat product diversity Index (%) G13	−	0.0266
	Per capita of pork (ton/person) G14	+	0.0204
	Growth rate of pork production (%)G15	+	0.0580

Note: "+" means positive index, "−" means negative index.

Indicators upstream of the industry chain consisted of (1) the breeding of good seeds. Adequate and high-quality seed supply is critical to the performance and quality of pig production. The paper adopted two indicators of breeding sow stock and the number of breeding farms to measure breeding status. (2) Feed production. Feed resource supply is vital to ensuring the stable supply of live pigs. We selected pig compound feed production and pig feed output value to characterize feed grain production capacity.

The development of the midstream pig industrial chain should comprise healthy pig feeding, steady pork supply, and waste utilization. (1) Pig health medical services are crucial safeguards for pigs' long-term health and development. The study chose the quantity of basic animal husbandry veterinary stations and the level of veterinary technology. (2) Farming systems. The breeding link is essential for maintaining a sufficient supply of pigs. Promoting machinery, increasing scale, and stable supplies are the main aims. We used total pig production, yield volatility, and labor productivity per person to gauge the stable supplies. Scale expansion is measured by the degree of large-scale breeding of various types of livestock and poultry, and the paper selected farmers with more than 500 pigs slaughtered as the indicator of large-scale production and then compared the total farmers to characterize the level of large-scale production. The total power of a unit's livestock machinery for pigs was used to calculate the mechanization rate. (3) Resource utilization. Green production is the key element of sustainable development. The integrated planting and breeding technique decreases pig breeding waste emissions and encourages resource recycling. As a result, the amount of pig dung produced was measured using the pig slaughter volume, and the nutrient content in pig manure was assessed using the pig excretion coefficient and the major nutrient content coefficient. Finally, the contribution rate of pig nitrogen nutrients, phosphorous nutrients, and potassium nutrients was determined by adding together the fertilizer needs of each province.

Finally, the industry chain downstream involves (1) slaughtering and processing. The processing industry is an integral part of the livestock products industry chain and enhances its value. The paper used the average output of processing enterprises to measure the regional slaughtering and processing capacity. (2) Product consumption. Pork consumption is the final link in the hog industry chain. This paper measured pork consumption levels by diversifying meat consumption, per capita pork possession, and pork growth rate.

4.2.2. Independent Variables

The main independent variable in this study was environmental regulation (ER). To measure ER, some researchers have used a single indicator such as per capita income [62], environmental investment [42], or treatment level of certain pollutants [63]. Other scholars adopted integrated evaluation indexes, such as comprehensive evaluation indexes based on energy intensity and recovery rate [64], the emission intensity of various pollutants [65], and environmental sustainability indicators provided by the International Network of Earth Science Information Centers [66]. Considering the availability of data, we referred to Hamamoto, who uses the natural logarithm of environmental expenditure as a proxy variable of environmental regulation [42].

Given that the two indicators mentioned above represent the overall level of local environmental regulation, they cannot focus on the perspective of environmental protection in the livestock industry. Environmental regulations are government rules that aim to safeguard the environment [67]. Therefore, considering the association between local environmental protection policies and the features of the area's population, economy, geography, and government aims, we drew on Chen et al. [68] to collect the number of environmental protection policies issued by the National and Local Agricultural and Rural Bureau (NARB) regarding environmental pollution concerns in animal husbandry as a proxy variable for central environmental regulation (CER) and local environmental regulation (LER).

4.2.3. Control Variables

Education (EDU) has historically served as a proxy for human capital development [30]. The hog industry chain will expand more generally as a result of the increase in human capital's impact on business productivity. This study measured education by looking at residents' average degree of education.

Industrial Structure (IS). Distinctions in industrial structure affect the access to heterogeneous regional resources, and regions with higher degrees of economic growth are more able to have access to high-level labor employment. This study used the ratio of primary industry output to regional GDP to represent industrial structure.

Urbanization Rate (UR). Urbanization implies the emigration of the rural populace and the resulting modifications in the way of life, consumer demand, and economic growth. With the growth in urban dwellers' standards, people's increasingly diverse demand for pork product quality leads to the green production behavior of farmers. We expressed the urbanization rate by the percentage of the urban population in a region at the end of the year.

Fixed Assets Investment (FAI). FAI will accelerate the change in industrial structure, market scale, and technological innovation of enterprises, which will provide capital expenditure for the development of pig enterprises, measured by the natural logarithm of fixed asset investment.

Infrastructure Construction (IC). Better regional infrastructure represents a higher consumption level of the local population and higher demand for product consumption, quality, and safety, which can better promote the development of the local hog industry. Therefore, this paper used the number of roads in miles to measure the level of local infrastructure.

4.2.4. Data Source and Variable Description

On account of the lack of data before 2005, relevant data for 2019 onwards are not yet available. Its data are excluded from the data sample as Hong Kong, Macao, and Taiwan data are not available, and the data for Tibet are severely limited. Thus, the panel data used in this paper utilizes data from 30 provincial administrative regions in China from 2005 to 2019. Our primary data are drawn from China's official statistical database, including the China Statistical Yearbook, China Agricultural Yearbook, China Animal Husbandry, and Veterinary Yearbook, China Feed Industry Yearbook, China Basic Unit Statistical Yearbook, State Intellectual Property Office, State Bureau of Statistics, Local Agricultural and Rural Bureau. The missing values were filled using the interpolation method. Table 3 is the variable definitions and descriptive statistical analysis.

Table 3. Descriptive statistics of variables.

	Definition (unit)	Mean	Std. Dev.	Min	Max
DPI	Comprehensive index of development of pig industry (-)	0.3337	0.1056	0.1138	0.5990
ER	Environmental protection expenditure (108 yuan)	103.7997	92.0150	2.8750	747.4400
EDU	Average years of education (year)	8.7380	0.9401	6.3441	12.1763
IS	Proportion of output value of one production (%)	10.6517	5.6530	0.2723	32.7347
UR	Urban population/total population (%)	54.0851	13.8343	26.8633	89.6125
IC	Highway mileage (104 km)	13.4720	7.5395	0.8100	33.7100
FAI	Total investment in fixed assets (108 yuan)	12,998.1100	12,138.2800	329.8100	67,082.6200
PP	Pork prices (yuan/kg)	22.6164	5.7051	10.8000	49.3700
PGDP	Per capita gross national product (104 yuan)	42,577.78	27,076.21	5052	164,220
TI	Number of agricultural green inventions authorized (item)	152.5933	242.8853	0	1678
LSF	Ratio of large-scale breeding (%)	1.6227	4.5197	0.0029	75.3846

5. Empirical Results

5.1. Evaluation Results of DPI

Table 4 shows the comprehensive index of DPI in various provinces. The average annual growth rate of the DPI of China from 2009 to 2020 is 2.01%, compared to 2.85%, 2.21%, and 0.96% for the main, middle-, and low-production regions, respectively. According to the ranking, Hunan reaches the highest average level of DPI (0.5346), followed by Sichuan and Guangdong (0.5234 and 0.50440, respectively), and Qinghai has the lowest quality of industrial chain (0.1712). From the mean value of production areas, the DPI of the main production zones is highest (0.4461), followed by the medium-sized (0.3130) and small-sized (0.2421) producing areas. This implies that the live pig industry's development level and the regional feeding scale are strongly correlated.

Table 4. The development level of the pig industry.

	Region	2005	2010	2015	2016	2017	2018	2019	Mean	Ranks
Main pig-production regions	Sichuan	0.3965	0.4842	0.5450	0.5773	0.5621	0.5900	0.4847	0.5234	2
	Hunan	0.3958	0.5096	0.5208	0.5565	0.5480	0.5878	0.4971	0.5346	1
	Henan	0.4016	0.4379	0.4575	0.4559	0.4381	0.5145	0.4532	0.4678	4
	Shandong	0.3509	0.4172	0.4669	0.4863	0.4875	0.5063	0.4445	0.4557	5
	Hubei	0.3200	0.4040	0.4191	0.4414	0.4434	0.5207	0.4645	0.4279	6
	Guangdong	0.3650	0.5142	0.4960	0.5253	0.5172	0.5885	0.5478	0.5044	3
	Hebei	0.3226	0.3327	0.3617	0.3650	0.3626	0.3916	0.3461	0.3621	11
	Yunnan	0.2866	0.4125	0.4178	0.4419	0.4545	0.4676	0.3839	0.4072	7
	Guangxi	0.2531	0.3531	0.3651	0.3731	0.4716	0.5390	0.4790	0.3868	9
	Jiangxi	0.2705	0.3760	0.3970	0.4131	0.4110	0.4171	0.3886	0.3910	8
Mean of main pig-producing regions		0.3363	0.4241	0.4447	0.4636	0.4696	0.5123	0.4489	0.4461	—
Mid-sized production regions	Jiangsu	0.2218	0.2856	0.3262	0.3371	0.3416	0.3747	0.3633	0.3166	17
	Anhui	0.2248	0.2912	0.3041	0.3129	0.3124	0.3013	0.2951	0.3040	19
	Liaoning	0.2406	0.3761	0.3748	0.3834	0.3915	0.4109	0.3612	0.3663	10
	Fujian	0.2624	0.3366	0.3360	0.3745	0.3423	0.3716	0.3529	0.3452	12
	Chongqing	0.2291	0.2832	0.3024	0.2974	0.2876	0.2698	0.2564	0.2928	20
	Guizhou	0.1845	0.3253	0.2756	0.2822	0.2841	0.2586	0.2239	0.2745	22
	Heilongjiang	0.2560	0.3411	0.3164	0.3324	0.3413	0.3108	0.3114	0.3282	13
	Zhejiang	0.2700	0.2758	0.1911	0.1928	0.1862	0.1931	0.1985	0.2561	23
	Jilin	0.2333	0.3198	0.3423	0.3598	0.3523	0.3760	0.3365	0.3251	14
	Shaanxi	0.2259	0.3448	0.3338	0.3367	0.3322	0.2768	0.2886	0.3211	16
Mean of mid-sized producing regions		0.2348	0.3180	0.3103	0.3209	0.3172	0.3144	0.2988	0.3130	—
Small-sized pig-production regions	Neimenggu	0.1778	0.2644	0.2639	0.2390	0.2963	0.2415	0.2498	0.2497	24
	Shanxi	0.1433	0.2540	0.2424	0.2387	0.2427	0.2631	0.2493	0.2447	25
	Gansu	0.1811	0.2800	0.3194	0.3244	0.3178	0.2891	0.2624	0.2834	21
	Hainan	0.2229	0.3245	0.3325	0.3429	0.2518	0.2625	0.2544	0.3150	18
	Xinjiang	0.1860	0.2227	0.2263	0.2364	0.2430	0.2332	0.2488	0.2362	26
	Tianjin	0.1855	0.2055	0.1952	0.1987	0.1641	0.1803	0.1748	0.2019	28
	Beiing	0.1784	0.1663	0.1709	0.1904	0.1823	0.2557	0.3538	0.2050	27
	Shanghai	0.4481	0.1648	0.1565	0.1513	0.1283	0.1138	0.1228	0.1919	29
	Qinghai	0.1586	0.1610	0.1851	0.1745	0.1945	0.1907	0.1616	0.1712	30
	Ningxia	0.1976	0.3468	0.3638	0.3619	0.3714	0.2359	0.2328	0.3216	15
Mean of small-sized pig-producing regions		0.2079	0.2390	0.2456	0.2458	0.2392	0.2266	0.2311	0.2421	—
Mean of all provinces		0.2597	0.3270	0.3335	0.3434	0.3420	0.3511	0.3263	0.2597	—

Note: For a more detailed analysis of each production area's situation, 30 provinces in China are divided into main, mid-sized, and small-sized pig-production regions according to the average pig production in descending order. The ranks are derived from the mean. Due to space constraints, the index of DPI only shows the years 2005, 2010, and 2015–2019. Source: Authors' estimations.

Figure 2a clearly shows the development trend of each province. It can be seen that the pig industry layout in China has obvious aggregation characteristics, with the main production area (red mark) mainly concentrated in the southwest, the middle-production area (green mark) concentrated in the east, and the low-production area (yellow mark) concentrated in the northwest. This is different from Zhong et al.'s observation that pig total factor productivity is greatest in the eastern region [69]. The reason is that the evaluation indexes of the pig industry are different. Compared with green production, this paper pays more attention to the development of the whole hog industry chain. Figure 2 also shows the pig industry development levels in 2005, 2010, 2010, and 2019, and it can be seen that the industry development levels of the 30 pig provinces are largely dominated by an upward trend, but there is a significant decline in DPI in 2019. The epidemic of African swine disease could be to blame. By the end of 2019, China had killed 1,193,000 pigs overall since the epidemic began in 2018. Because of the severe imbalance between supply and demand brought on by the abrupt decrease in hog stock, China experienced a protracted oversupply problem. Additionally, as a result of farmers' fear of swine fever, many of them downsized or withdrew from the market, which not only caused a backlog of material stocks upstream in the hog industry chain but also made the supply gap downstream in the chain worse.

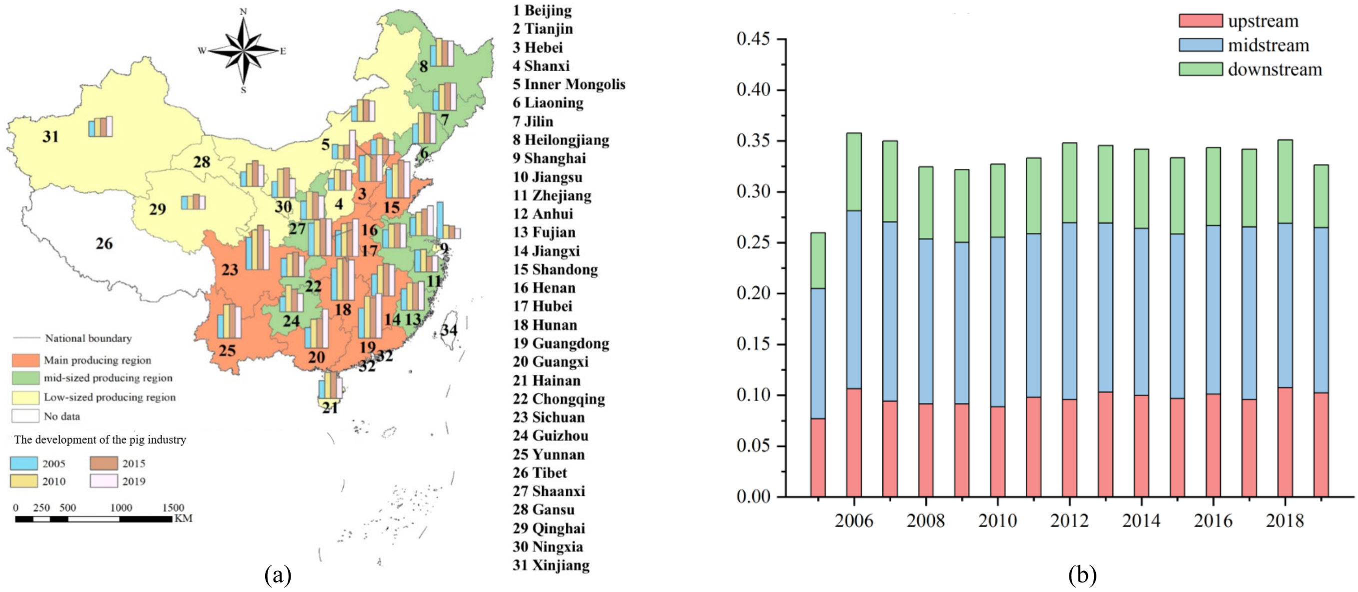

Figure 2. The DPI by province and industrial chain links. Note: Figure (**a**) shows the development trend chart of pig industry in 30 provinces in China in 2005, 2010, 2015 and 2019. Figure (**b**) shows the contribution of the upsteam, midsteam and downsteam to the pig industry from 2005 to 2019.

Figure 2b shows the DPI of different links in the pig industry chain, with the downstream being the lowest, and the contribution of the middle as the core link being the largest. The overall quality of the industry chain showed an upward trend with time but declined in 2006, 2012, and 2018. Looking back at the Chinese pig industry's development history, we recognize that the pig industry has been affected by the pathogenic blue-ear disease, pig cycle, and African swine fever in 2006, 2012, and 2018, respectively. This shows that external impacts have a detrimental impact on China's pig industry's development.

5.2. Benchmark Empirical Results

The estimates based on OLS, FE, and FGLS tests, and system GMM are reported by models 1–4 (Table 5). As you can see, all four models obtain nearly the same results. The value of AR(1) is less than 0.1, and AR(2) is greater than 0.1 in model 4. This implies that the perturbation term has no autocorrelation [70]. The p-value of the Hansen test statistic of 1.000 shows that the hypothesis of the tool variable is correct and cannot be rejected. The chosen GMM model is feasible, as shown by the estimated coefficient of the first-order lag of explanatory variables in the GMM model, which is between OLS and FE.

The measured coefficient in model 4 shows that although the linear term of ER is notably negative, its squared ER2 is extremely positive in all models. The findings support the "U" dynamic model of DPI increase with ER; hypotheses 1 and 2 are also confirmed. This discovery echoes that of Minton and Schrand [59], who pointed out a non-linear connection between environmental regulation and the shift in Chinese industrial development patterns. Environmental regulation slows the growth of the pig business in the early stages of environmental policy implementation through "cost effects" and "crowding out effects". As the regulation level increases, the government will limit the emission behavior of a few heavy polluters or even force companies out of production. Some pollution-intensive companies and farmers will also withdraw from the market due to the high environmental costs. Eventually, some companies and farmers will have to upgrade their pollution control equipment and invest in research and development to meet regulatory requirements. The "anti-driving effect" and "compensating effect" are becoming more and more prominent.

Table 5. Regressions of ER on DPI.

VARIABLES	(1) DPI	(2) DPI	(3) DPI	(4) DPI	(5) DPI	(6) DPI	(7) DPI
	OLS	FE	FGLS	GMM	Main origin	Mid-yield	Low-yield
DPI	0.8621 ***	0.3500 ***	0.8659 ***	0.8165 ***	0.8739 ***	0.8703 ***	0.7927 ***
	(0.0230)	(0.0640)	(0.0223)	(0.0503)	(0.0319)	(0.0617)	(0.0710)
lnER	−0.0685 ***	−0.0578 ***	−0.0618 ***	−0.0631 ***	−0.1099 ***	−0.0327	−0.0401 ***
	(0.0152)	(0.0152)	(0.0140)	(0.0186)	(0.0358)	(0.0202)	(0.0103)
lnER2	0.0076 ***	0.0045 **	0.0065 ***	0.0070 ***	0.0101 ***	0.0043	0.0054 ***
	(0.0017)	(0.0017)	(0.0016)	(0.0021)	(0.0039)	(0.0026)	(0.0015)
lnEDU	0.0810 **	0.2113 **	0.0720 **	0.0874	0.0366	0.0591	0.1022 *
	(0.0372)	(0.0865)	(0.0301)	(0.0550)	(0.0563)	(0.0423)	(0.0546)
lnIS	0.0025	−0.0322 *	0.0034	0.0053	0.0015	0.0074	0.0106
	(0.0042)	(0.0174)	(0.0040)	(0.0043)	(0.0148)	(0.0063)	(0.0070)
lnUR	−0.0449 **	−0.0556	−0.0273 *	−0.0365	0.0534	−0.0247 **	−0.0735 ***
	(0.0194)	(0.0518)	(0.0157)	(0.0270)	(0.0332)	(0.0107)	(0.0263)
lnIC	0.0070	−0.0356	0.0090 *	0.0064	0.0398 ***	−0.0093	−0.0173 **
	(0.0058)	(0.0343)	(0.0051)	(0.0077)	(0.0138)	(0.0092)	(0.0077)
lnFAI	0.0082 *	0.0190	0.0082 **	0.0084	−0.0159 **	0.0036	0.0055
	(0.0045)	(0.0126)	(0.0035)	(0.0059)	(0.0076)	(0.0024)	(0.0093)
lnPP	−0.0818 ***	−0.0435 ***	−0.0788 ***	−0.0362 ***	0.0982 ***	0.0427	−0.0808 **
	(0.0102)	(0.0102)	(0.0086)	(0.0080)	(0.0190)	(0.0352)	(0.0337)
L.lnPP	0.0085	−0.0030	0.0083	0.0178	−0.1868 **	−0.0975 **	−0.0173
	(0.0103)	(0.0112)	(0.0085)	(0.0120)	(0.0827)	(0.0484)	(0.0344)
Constant	0.3336 ***	0.2714	0.2584 ***	0.1078	−0.1959	0.2303	0.2763 ***
	(0.0750)	(0.1693)	(0.0592)	(0.0912)	(0.2159)	(0.1497)	(0.0803)
Obs	420	420	420	390	130	130	130
Number of N	30	30	30	30	10	10	10
A(1)				−4.10 (0.000)	−2.62 (0.009)	−2.94 (0.003)	−2.59 (0.010)
A(2)				0.72 (0.472)	0.05 (0.963)	0.69 (0.493)	−0.07 (0.945)
Hansen				25.58 (1.000)	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. AR (1) and AR (2) are used to test the difference autocorrelation of the perturbation term. Generally, the first-order difference of the perturbation term is allowed to have autocorrelation; that is, the p-value of AR (1) is less than 0.1. However, the second-order difference of the perturbation term is not allowed to have autocorrelation; that is, the p-value of AR (2) should be greater than 0.1 [70].

We concluded from the control variable coefficients that schooling was significantly positive at the 5% significant level, indicating that it considerably benefited DPI. In the knowledge economy, knowledge is the primary driver of economic growth. Education is becoming increasingly vital as a means of investing in human capital, contributing to the advancement of production technology, and encouraging industrial innovation [71,72]. Through technical improvement and industrial innovation, EDU raises DPI. However, at the 1% level, pork prices were notably negative. The conclusion was in line with Wu et al. 's observation that hog prices had a detrimental impact on eco-efficiency [40].

5.3. Heterogeneity Analysis

Different provinces show considerable discrepancies in the number of pigs. We divide 30 provinces into main, medium-, and low-production areas. In Table 5, models 5–7 show the regression results of different production areas based on system GMM. From the estimation coefficient, it is clear that ER affects DPI significantly in a U-shape in low- and high-producing locations but not in mid-producing areas. The main producing location is frequently the focal point of the government's pig supply assurance and environmental rules, which could be the cause. When the initial environmental regulation is increased, the operating cost of the farmers will eventually increase, causing harm to the scale of production, and the late internal vitality will gradually increase. Green technological innovation will accelerate the creation of the innovation compensation effect. For low-production areas, the government prefers a strategy of environmental protection to a long-term policy of stable production capacity. Therefore, companies and farmers in low-production areas prefer to pay the cost of emission of small amounts of pollutants rather than long-term investment such as research and development. Under environmental regulations, low-production areas are mainly experiencing short-term negative shocks.

5.4. Robustness Checks

Given that the proxy for ER is not uniform, we utilized per capita income as an alternative to measuring ER [62]. Models 8 and 9 in Table 6 represent the outcomes after replacing the dependent variable using FGLS and GMM. We discovered that the key variables' significance and sign are similar to the basic regression, indicating that our paper's findings are reliable.

Table 6. Results of robustness test.

VARIABLES	(8) DPI	(9) DPI	(10) DPI	(11) DPI
	FGLS	GMM	FGLS	GMM
L.DPI	0.8853 ***	0.7879 ***	0.8702 ***	0.8530 ***
	(0.0221)	(0.0631)	(0.0218)	(0.0422)
lnPGDP	−0.0074 *	−0.0160 **		
	(0.0040)	(0.0104)		
lnPGDP2	0.0007 ***	0.0009 **		
	(0.0002)	(0.0005)		
L.lnER			−0.0566 ***	−0.0413 ***
			(0.0102)	(0.0137)
L.lnER2			0.0068 ***	0.0058 ***
			(0.0013)	(0.0016)
lnEDU	−0.3577 ***	−0.3233 *	0.0791 ***	0.0658
	(0.0799)	(0.1668)	(0.0293)	(0.0409)
lnIS	0.0167 ***	0.0156 **	0.0050	0.0068 *
	(0.0037)	(0.0079)	(0.0039)	(0.0040)
lnUR	0.0558 *	0.0271	−0.0300 *	−0.0307
	(0.0296)	(0.0450)	(0.0155)	(0.0225)
lnIC	0.0130 ***	0.0055	0.0069	0.0008
	(0.0041)	(0.0040)	(0.0050)	(0.0067)
lnFAI	0.0201	−0.0086	0.0056 *	0.0047
	(0.0222)	(0.0383)	(0.0033)	(0.0049)
lnPP	0.0051	0.0069	−0.0754 ***	−0.0387 ***
	(0.0043)	(0.0058)	(0.0086)	(0.0098)
L.lnPP	0.0069 *	0.0006	0.0076	0.0129
	(0.0038)	(0.0065)	(0.0084)	(0.0130)
Constant	1.8855 ***	1.7183 **	0.2394 ***	0.1167
	(0.3858)	(0.8631)	(0.0588)	(0.0738)
Observations	420	360	420	390
Number of N	30	30	30	30
AR (1)		−3.67 (0.000)		−4.23 (0.000)
AR (2)		0.53 (0.598)		0.47 (0.635)
Hansen		11.64 (1.000)		25.45 (1.000)

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Another key point to remember is that the effect of ER on DPI may have a time lag. As a result, we applied a one-period lag to the ER and re-regressed the explanatory variables. The FGLS and GMM results for Models 10 and 11, respectively, demonstrate that the ER with a one-period lag continues to have a favorable U-shaped association with the DPI.

5.5. Moderating Effect Analysis

According to the theoretical analysis framework of Section 3, this study selected the logarithms of technological innovation (TI) and large-scale farming (LSF) to form two interaction terms with ER, and then FGLS and GMM were used for regression analysis. Table 7 displays the regression results after adding interaction elements.

Table 7. The mediating effect.

VARIABLES	(12) DPI	(13) DPI	(14) DPI	(15) DPI
	FGLS	GMM	FGLS	GMM
L.DPI	0.8585 ***	0.7131 ***	0.8644 ***	0.8260 ***
	(0.0227)	(0.0807)	(0.0215)	(0.0426)
lnER	−0.0473 ***	−0.0491 *	−0.0435 ***	−0.0563 ***
	(0.0140)	(0.0259)	(0.0124)	(0.02192)
lnTI	−0.0096	−0.0365		
	(0.0071)	(0.0260)		
lnER*LnTI	0.0030 *	0.0106 *		
	(0.0016)	(0.0059)		
lnLSF			−0.0323 ***	−0.0258
			(0.0058)	(0.0035)
lnER*lnLSF			0.0069 ***	0.0059 *
			(0.0012)	(0.0095)
lnER2	0.0031	−0.0019	0.0036 **	0.0055 **
	(0.0020)	(0.0050)	(0.0014)	(0.0027)
lnEDU	0.0852 ***	0.1533	0.1230 ***	0.0569
	(0.0327)	(0.1106)	(0.0380)	(0.0878)
lnIS	0.0059	0.0088 *	0.0031	0.0027
	(0.0040)	(0.0048)	(0.0038)	(0.0061)
lnUR	−0.0253	−0.0463	−0.0229	−0.0144
	(0.0158)	(0.0418)	(0.0156)	(0.0221)
lnIC	0.0094 *	0.0180 *	0.0114 **	0.0128
	(0.0050)	(0.0095)	(0.0048)	(0.0090)
lnFAI	0.0053	0.0071	0.0136 ***	0.0098
	(0.0040)	(0.0117)	(0.0038)	(0.0095)
lnPP	−0.0775 ***	−0.0290 ***	−0.0721 ***	−0.0059
	(0.0085)	(0.0091)	(0.0083)	(0.0491)
L.lnPP	0.0057	0.0189	0.0124	−0.0052
	(0.0085)	(0.0121)	(0.0084)	(0.0435)
Constant	0.2350 ***	0.0568	0.0152	0.0345
	(0.0607)	(0.1328)	(0.0803)	(0.1864)
Observations	420	390	420	390
Number of N	30	30	30	30
A(1)		−3.75 (0.000)		−3.91 (0.000)
A(2)		0.57 (0.566)		0.74 (0.460)
Hansen		24.25 (0.995)		6.44 (1.000)

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Firstly, the estimated coefficient for the interaction term of ER and TI in models 12 and 13 are significantly positive at 10%, respectively. TI greatly lessens the detrimental impact of ER on DPI. The negative effect of ER on DPI increased by 0.30–1.06% for every 1% increase in the proportion of TI. The conclusion was in line with Wang et al. [73]. The green innovation behavior of pig breeding subjects can help the breeding subjects to carry out green production, decrease the pollution cost, and improve the green production efficiency of pig farmers. Improvements in technology can speed up the arrival of the “innovation compensation effect” and reduce the amount of time that environmental regulations must show the “cost-effective effect” to promote the development of the live pig industry chain at a higher level.

Secondly, the estimated coefficients of ER and LSF interaction terms in model 14 and model 15 are significantly positive at 1% and 10%, respectively. The results showed that LSF significantly reduces the negative effects of ER on DPI. The negative effect of ER on DPI increased by 0.59–0.69% for every 1% increase in the proportion of LSF. The reason may be that large-scale pig farms have higher waste disposal rates and lower pollution levels than free-range farms. Under the same environmental regulation framework, large-scale pig farms can better utilize their advantages to expedite the arrival of the inflection point of the innovation offset effect. Large-scale breeding is crucial to the environmentally friendly and long-term growth of the pig industry.

Even though the pig industry has experienced numerous external shocks recently, the implementation of large-scale transformation and an upgrading strategy improves the risk resistance ability of the industrial chain as a whole, weakening the short-term "compliance costs effect" caused by the environmental regulation of negative effects, accelerating the formation of the "innovation effect", and finally enhancing the development of the overall level of the pig industry chain.

5.6. Further Discussion

To master how provincial governments will implement national environmental regulation, we collected the number of environmental policies about livestock and poultry released by the official government website. We brought central environmental policy (CER) and local environmental regulation (LER) into the model as new ER indicators. The outcomes are displayed in Table 8. Model 16 shows that the CER and DPI continue to have a U-shaped connection.

Table 8. Influence of animal husbandry environmental policy on DPI.

VARIABLES	(16) DPI	(17) DPI	(18) DPI	(19) DPI	(20) DPI
	GMM	GMM	Main origin	Mid-yield	Low-yield
L.DPI	0.7918 ***	0.7790 ***	0.6017 ***	0.6675 ***	0.7823 ***
	(0.0450)	(0.0721)	(0.1052)	(0.1716)	(0.1465)
CER	−0.0023 *				
	(0.0012)				
CER2	0.0001 *				
	(0.0000)				
LER		−0.0019 ***	0.0023 ***	−0.0023 **	−0.0034 **
		(0.0007)	(0.0009)	(0.0011)	(0.0016)
LER2		0.0000 **	−0.0000 **	0.0000 *	0.0001 *
		(0.0000)	(0.0000)	(0.0000)	(0.0000)
lnEDU	0.0556	0.0691	0.2235	0.1429 *	0.0639
	(0.0707)	(0.0773)	(0.1371)	(0.0819)	(0.0872)
lnIS	0.0092	0.0076	−0.0110	0.0212	0.0020
	(0.0059)	(0.0057)	(0.0311)	(0.0134)	(0.0112)
lnUR	−0.0275	−0.0288	−0.0033	−0.0338	−0.0607
	(0.0398)	(0.0355)	(0.0652)	(0.0312)	(0.0527)
lnIC	0.0018	0.0053	0.0515	−0.0210	−0.0051
	(0.0093)	(0.0080)	(0.0360)	(0.0216)	(0.0086)
lnFAI	0.0131 *	0.0110 **	−0.0213	0.0048	0.0051
	(0.0067)	(0.0055)	(0.0172)	(0.0071)	(0.0059)
lnPP	−0.0745 ***	−0.0095	−0.0832 ***	0.0168	0.0464 *
	(0.0140)	(0.0180)	(0.0133)	(0.0145)	(0.0262)
L.lnPP	−0.0042	0.0100	0.0281 **	0.0172	−0.0139
	(0.0077)	(0.0134)	(0.0140)	(0.0143)	(0.0171)
Constant	0.1754 *	−0.0738	−0.0678	−0.1885*	0.0440
	(0.1004)	(0.0785)	(0.3905)	(0.1065)	(0.1308)
Observations	420	390	130	130	130
Number of N	30	30	10	10	10
A(1)	−3.90 (0.000)	−3.95 (0.000)	−2.5 1(0.012)	−2.47 (0.014)	−2.28 (0.023)
A(2)	0.51 (0.613)	0.43 (0.670)	1.44 (0.149)	0.55 (0.582)	0.18 (0.858)
Hansen	26.87 (1.000)	23.28 (0.225)	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

It is worth noting that there are still some variations in how local governments implement national environmental legislation. According to the regression results from models 17–20, LER showed a U-shaped relationship for all DPI for non-primary production areas, the same as the total sample regression results in model 17. However, an inverted U-shaped relationship is shown for the main production areas. A possible reason for this is that the efficiency of local government regulation in key production regions frequently varies with economic, political, and ecological aims. Due to "GDP competitiveness" and "vegetable basket responsibility", the government may also develop subsidy policies to promote farming and expand farming, while enforcing environmental legislation policies. In doing so, it will lessen the financial pressure on farmers to comply with environmental regulations while simultaneously achieving environmental protection and boosting the pig industry's sustainable development. This is in line with the findings of Zhao et al., who postulate that the impact of ER is positively correlated in those with high levels of economic development and U-shaped in other places [74]. This shows that under the direction of varied aims, the consequences of environmental control in key production areas produce distinct results.

When reviewing the regional heterogeneity results of models 5–6, the regression results of total environmental input indicators on regional environmental regulation policies are also controversial in the medium-production areas. The possible reason is that most of the middle-producing regions are eastern coastal cities with a concentration of people and industrial development, and industry, as the main output of GDP in the region, is the focus of environmental inputs, which also crowd out the environmental inputs of livestock and poultry farming. From the regression results of the environmental policy for livestock and poultry in the mid-production areas, the implementation of environmental policy in the mid-production areas still follows the assumption of the short-term cost effect and the long-term innovation compensation effect.

6. Conclusions

This study explores the influencing effects of ER on the DPI under multiple dilemmas by using FGLS and system-GMM, using panel data from 30 Chinese provinces collected from 2005 to 2019. To begin with, considering the longer value chain and more multi-dimensional objectives of the pig industry, we created the assessment indicator system for the development of the pig industry chain focused on the seven links of "fine seed breeding, feed production, pig health, pig breeding, resource utilization, slaughter and processing, and consumption" with the entropy weight method. Experimental findings indicate that DPI in the main production areas is higher than in the mid-sized and low-sized production regions. The industrial chain's middle link has a big impact on DPI, as seen from an industrial chain perspective. Secondly, the empirical findings indicate that in the primary- and low-pig-production zones, ER and DPI have a positive U-shaped connection. Furthermore, to investigate the moderating effect relationship between ER and DPI, the interaction variables of TI and LSF with ER were introduced, respectively. It was discovered that TI and LSF might lessen the detrimental effects of ER on DPI. That is to say, the large-scale transformation strategy's combined effects hasten the creation of the "Porter hypothesis" and the coming of the environmental regulatory tipping point. Furthermore, there are also considerable differences in how local governments apply national environmental policies. The LER has an inverted U-shaped connection with DPI in the main producing areas and a U-shaped in the non-major producing areas. Based on the aforementioned empirical findings, this article makes the following policy recommendations.

(1) The gap in how local governments apply environmental regulation suggests that the environmental supervision mechanism of livestock and poultry needs to be improved. Localities implemented a discretionary decision-making mechanism based on the pig cycle to balance the policy's multiple objectives. Such subjective government intervention, in turn, tended to accelerate the pig-cycle process. Therefore, it is essential to build an environmental performance evaluation system that takes into

account local conditions as well as scientifically constructs and enhances the rules and regulations on animal husbandry environmental protection.

(2) Scale transformation benefits the growth of the pig industry. Coordination between short- and long-term policies is essential. Short-term policies focus on the scale-up process of pig production. The long-term policy priority should be to encourage firms and farmers to innovate technologically, raise fundamental R&D investment, and promote green farming via the "innovation compensation" effect, to balance rising production costs. In the transitional period of technical innovation and industrial transformation, we should optimize the centralized treatment mechanism of pig manure pollution under government subsidies, support the large-scale transformation of the industry, and assure stable production and supply.

(3) The breeding link is an important link to the development of the industrial chain. Therefore, it is crucial to improve the risk management ability of pig breeding. First of all, based on the core regulatory indicators of breeding sows, dynamic assessment should be carried out in provinces and regions with sudden epidemic risks. Secondly, an industrial chain coordination mechanism should be established to strengthen the comprehensive coordination of factor supply and price stabilization of node enterprises or farmers on the chain through technology, market, and financing relations. Thirdly, it should strengthen the inter-temporal transformation mechanism of systemic risk in the industrial chain based on "live pig futures + insurance," and guide financial institutions in providing risk management services that encompass the entire industrial chain, such as hedging and insurance.

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Abbreviations

ER	Environmental regulation
DPI	development of the pig industry
EDU	Education
IS	Industrial Structure
UR	Urbanization Rate
FAI	Fixed Assets Investment
IC	Infrastructure Construction
TI	Technology Innovation
LSF	large-scale farming
CER	Central environmental regulation
LER	Local environmental regulation

References

1. Schiffman, S.S.; Williams, C.M. Science of Odor as a Potential Health Issue. *J. Environ. Qual.* **2005**, *34*, 129–138.
2. Steinfeld, H.; Gerber, P.; Wassenaar, T.D.; Castel, V.; Rosales, M.; Rosales, M.; de Haan, C. *Livestock's Long Shadow: Environmental Issues and Options*; Food & Agriculture Organization: Rome, Italy, 2006; ISBN 92-5-105571-8.
3. Baker, A. Fluorescence Properties of Some Farm Wastes: Implications for Water Quality Monitoring. *Water Res.* **2002**, *36*, 189–195. [CrossRef]
4. Clemêncio, C.; Viegas, M.; Nadais, H. Nitrogen and Phosphorus Discharge of Animal Origin in the Baixo Vouga: A Spatial Data Analysis. *Sci. Total Environ.* **2014**, *490*, 1091–1098. [CrossRef] [PubMed]
5. Xiao, H.; Wang, J.; Oxley, L.; Ma, H. The Evolution of Hog Production and Potential Sources for Future Growth in China. *Food Policy* **2012**, *37*, 366–377. [CrossRef]
6. Li, C.; Wan, J.; Xu, Z.; Lin, T. Impacts of Green Innovation, Institutional Constraints and Their Interactions on High-Quality Economic Development across China. *Sustainability* **2021**, *13*, 5277. [CrossRef]
7. Wang, G.; Shen, Y.; Li, C.; Zhu, Q.; ZhanBota, A. The Regulatory Effect of Herd Structure on Pig Production under the Environmental Regulation. *PLoS ONE* **2022**, *17*, e0266687. [CrossRef]
8. Ouyang, X.; Li, Q.; Du, K. How Does Environmental Regulation Promote Technological Innovations in the Industrial Sector? Evidence from Chinese Provincial Panel Data. *Energy Policy* **2020**, *139*, 111310. [CrossRef]
9. Tian, X.L.; Guo, Q.G.; Han, C.; Ahmad, N. Different Extent of Environmental Information Disclosure across Chinese Cities: Contributing Factors and Correlation with Local Pollution. *Glob. Environ. Change* **2016**, *39*, 244–257. [CrossRef]
10. Jaffe, A.B. Environmental Regulation and the Competitiveness of U.S. Manufacturing: What Does the Evidence Tell Us? *J. Econ. Lit.* **1995**, *33*, 132–163.
11. Yasmeen, H.; Tan, Q.; Zameer, H.; Tan, J.; Nawaz, K. Exploring the Impact of Technological Innovation, Environmental Regulations and Urbanization on Ecological Efficiency of China in the Context of COP21. *J. Environ. Manag.* **2020**, *274*, 111210. [CrossRef]
12. Zhang, Y.; Huang, G. Grey Lotka-Volterra Model for the Co-Evolution of Technological Innovation, Resource Consumption, Environmental Quality, and High-Quality Industrial Development in Shaanxi Province, China. *Environ. Sci. Pollut. Res.* **2021**, *28*, 57751–57768. [CrossRef] [PubMed]
13. Li, B.; Liu, Z. Measurement and Evolution of High-Quality Development Level of Marine Fishery in China. *Chin. Geogr. Sci.* **2022**, *32*, 251–267. [CrossRef] [PubMed]
14. Liu, F.; Wang, C.; Zhang, Y.; Zhou, S.; Yang, Y.; Wu, X.; Hu, F.; Liu, C. Data-Driven Analysis and Evaluation of Regional Agriculture for High-Quality Development of Anhui Province in the Yangtze River Delta. *Environ. Sci. Pollut. Res.* **2022**, *29*, 22490–22503. [CrossRef] [PubMed]
15. Zhang, X.; Guo, W.; Bashir, M.B. Inclusive Green Growth and Development of the High-Quality Tourism Industry in China: The Dependence on Imports. *Sustain. Prod. Consum.* **2022**, *29*, 57–78. [CrossRef]
16. Liu, Y.; Liu, M.; Wang, G.; Zhao, L.; An, P. Effect of Environmental Regulation on High-Quality Economic Development in China—An Empirical Analysis Based on Dynamic Spatial Durbin Model. *Environ. Sci. Pollut. Res.* **2021**, *28*, 54661–54678. [CrossRef] [PubMed]
17. Dong, X.; Brown, C.; Waldron, S.; Zhang, J. Asymmetric Price Transmission in the Chinese Pork and Pig Market. *Br. Food J.* **2018**, *120*, 120–132. [CrossRef]
18. Yan, B.; Yan, J.; Shi, W.; Li, Y. Study on the Comprehensive Comparative Advantages of Pig Production and Development in China Based on Geographic Information System. *Clean Technol. Environ. Policy* **2020**, *22*, 105–117. [CrossRef]
19. Lanoie, P.; Patry, M.; Lajeunesse, R. Environmental Regulation and Productivity: Testing the Porter Hypothesis. *J. Product. Anal.* **2008**, *30*, 121–128. [CrossRef]
20. Rubashkina, Y.; Galeotti, M.; Verdolini, E. Environmental Regulation and Competitiveness: Empirical Evidence on the Porter Hypothesis from European Manufacturing Sectors. *Energy Policy* **2015**, *83*, 288–300. [CrossRef]
21. Jorgenson, D.W.; Wilcoxen, P.J. Environmental Regulation and US Economic Growth. *Rand J. Econ.* **1990**, *21*, 314–340. [CrossRef]
22. Kneller, R.; Manderson, E. Environmental Regulations and Innovation Activity in UK Manufacturing Industries. *Resour. Energy Econ.* **2012**, *34*, 211–235. [CrossRef]
23. Ramanathan, R.; Ramanathan, U.; Bentley, Y. The Debate on Flexibility of Environmental Regulations, Innovation Capabilities and Financial Performance–A Novel Use of DEA. *Omega* **2018**, *75*, 131–138. [CrossRef]
24. Yuan, B.; Xiang, Q. Environmental Regulation, Industrial Innovation and Green Development of Chinese Manufacturing: Based on an Extended CDM Model. *J. Clean. Prod.* **2018**, *176*, 895–908. [CrossRef]
25. Berman, E.; Bui, L.T. Environmental Regulation and Labor Demand: Evidence from the South Coast Air Basin. *J. Public Econ.* **2001**, *79*, 265–295. [CrossRef]
26. Sheng, J.; Zhou, W.; Zhang, S. The Role of the Intensity of Environmental Regulation and Corruption in the Employment of Manufacturing Enterprises: Evidence from China. *J. Clean. Prod.* **2019**, *219*, 244–257. [CrossRef]
27. Palmer, K.; Oates, W.E.; Portney, P.R. Tightening Environmental Standards: The Benefit-Cost or the No-Cost Paradigm? *J. Econ. Perspect.* **1995**, *9*, 119–132. [CrossRef]
28. Porter, M.E. America's Green Strategy. *Entific Am.* **1991**, *264*, 193–246. [CrossRef]
29. Ambec, S.; Cohen, M.A.; Elgie, S.; Lanoie, P. The Porter Hypothesis at 20: Can Environmental Regulation Enhance Innovation and Competitiveness? *Rev. Environ. Econ. Policy* **2013**, *7*, 2–22. [CrossRef]

30. Qiu, S.; Wang, Z.; Geng, S. How Do Environmental Regulation and Foreign Investment Behavior Affect Green Productivity Growth in the Industrial Sector? An Empirical Test Based on Chinese Provincial Panel Data. *J. Environ. Manag.* **2021**, *287*, 112282. [CrossRef] [PubMed]
31. Wang, Y.; Sun, X.; Guo, X. Environmental Regulation and Green Productivity Growth: Empirical Evidence on the Porter Hypothesis from OECD Industrial Sectors. *Energy Policy* **2019**, *132*, 611–619. [CrossRef]
32. Eskeland, G.S.; Harrison, A.E. Moving to Greener Pastures? Multinationals and the Pollution Haven Hypothesis. *J. Dev. Econ.* **2003**, *70*, 1–23. [CrossRef]
33. Neumayer, E. Pollution Havens: An Analysis of Policy Options for Dealing with an Elusive Phenomenon. *J. Environ. Dev.* **2001**, *10*, 147–177. [CrossRef]
34. Herath, D.; Weersink, A.; Carpentier, C.L. Spatial Dynamics of the Livestock Sector in the United States: Do Environmental Regulations Matter? *J. Agric. Resour. Econ.* **2005**, *30*, 45–68. [CrossRef]
35. Millimet, D.L.; List, J.A. A Natural Experiment on the 'Race to the Bottom'Hypothesis: Testing for Stochastic Dominance in Temporal Pollution Trends. *Oxf. Bull. Econ. Stat.* **2003**, *65*, 395–420. [CrossRef]
36. Naylor, R.; Steinfeld, H.; Falcon, W.; Galloway, J.; Smil, V.; Bradford, E.; Alder, J.; Mooney, H. Losing the Links between Livestock and Land. *Science* **2005**, *310*, 1621–1622. [CrossRef]
37. Lawley, C.; Furtan, H. The Political Trade-off between Environmental Stringency and Economic Development in Rural America. *J. Reg. Sci.* **2008**, *48*, 547–566. [CrossRef]
38. Pan, D.; Zhou, Y.; Zhang, L. Environmental Regulation and Location Dynamics of the Livestock Industry: Evidence from 279 Chinese Prefecture-Level Cities. *China Agric. Econ. Rev.* **2022**, *14*, 367–394. [CrossRef]
39. Lu, Y.; Tan, Y.F.; Wang, H.M. Impact of environmental regulation on green technology adoption by farmers microscopic investigation evidence from pig breeding in China. *Front. Environ. Sci.* **2022**, *10*, 885933. [CrossRef]
40. Wu, Q.; Xu, L.; Geng, X. Ecological Efficiency of Hog Scale Production under Environmental Regulation in China: Based on an Optimal Super Efficiency SBM-Malmquist–Tobit Model. *Environ. Sci. Pollut. Res.* **2022**, *29*, 53088–53106. [CrossRef]
41. Crafts, N. Regulation and Productivity Performance. *Oxf. Rev. Econ. Policy* **2006**, *22*, 186–202. [CrossRef]
42. Hamamoto, M. Environmental Regulation and the Productivity of Japanese Manufacturing Industries. *Resour. Energy Econ.* **2006**, *28*, 299–312. [CrossRef]
43. Porter, M.E.; van der Linde, C. Toward a New Conception of the Environment-Competitiveness Relationship. *J. Econ. Perspect.* **1995**, *9*, 97–118. [CrossRef]
44. Galloway, E.; Johnson, E.P. Teaching an Old Dog New Tricks: Firm Learning from Environmental Regulation. *Energy Econ.* **2016**, *59*, 1–10. [CrossRef]
45. Mohr, R.D. Technical Change, External Economies, and the Porter Hypothesis. *J. Environ. Econ. Manag.* **2002**, *43*, 158–168. [CrossRef]
46. Copeland, B.R.; Taylor, M.S. Trade, Growth, and the Environment. *J. Econ. Lit.* **2004**, *42*, 7–71. [CrossRef]
47. Bohringer, C.; Moslener, U.; Oberndorfer, U.; Ziegler, A. Clean and Productive? Empirical Evidence from the German Manufacturing Industry. *Res. Policy* **2012**, *41*, 442–451. [CrossRef]
48. Hu, W.; Wang, D. How Does Environmental Regulation Influence China's Carbon Productivity? An Empirical Analysis Based on the Spatial Spillover Effect. *J. Clean. Prod.* **2020**, *257*, 120484. [CrossRef]
49. Yuan, B.; Ren, S.; Chen, X. Can Environmental Regulation Promote the Coordinated Development of Economy and Environment in China's Manufacturing Industry?–A Panel Data Analysis of 28 Sub-Sectors. *J. Clean. Prod.* **2017**, *149*, 11–24. [CrossRef]
50. Bai, J.; Lu, J.; Li, S. Fiscal Pressure, Tax Competition and Environmental Pollution. *Environ. Resour. Econ.* **2019**, *73*, 431–447. [CrossRef]
51. Falavigna, G.; Manello, A.; Pavone, S. Environmental Efficiency, Productivity and Public Funds: The Case of the Italian Agricultural Industry. *Agric. Syst.* **2013**, *121*, 73–80. [CrossRef]
52. Wang, X.; Dadouma, A.; Chen, Y.; Sui, P.; Gao, W.; Jia, L. Sustainability Evaluation of the Large-Scale Pig Farming System in North China: An Emergy Analysis Based on Life Cycle Assessment. *J. Clean. Prod.* **2015**, *102*, 144–164. [CrossRef]
53. Wang, Z.X.; Li, D.D.; Zheng, H.H. The External Performance Appraisal of China Energy Regulation: An Empirical Study Using a TOPSIS Method Based on Entropy Weight and Mahalanobis Distance. *Int. J. Environ. Res. Public. Health* **2018**, *15*, 236. [CrossRef] [PubMed]
54. Zhang, M.; Li, B. How to Improve Regional Innovation Quality from the Perspective of Green Development? Findings From Entropy Weight Method and Fuzzy-Set Qualitative Comparative Analysis. *IEEE Access* **2020**, *8*, 32575–32586. [CrossRef]
55. Ghoddousi, P.; Nasirzadeh, F.; Hashemi, H. Evaluating Highway Construction Projects' Sustainability Using a Multicriteria Group Decision-Making Model Based on Bootstrap Simulation. *J. Constr. Eng. Manag.* **2018**, *144*, 04018092. [CrossRef]
56. He, L.; Du, Y.; Wu, S.; Zhang, Z. Evaluation of the Agricultural Water Resource Carrying Capacity and Optimization of a Planting-Raising Structure. *Agric. Water Manag.* **2021**, *243*, 106456. [CrossRef]
57. Zhou, W.; Pei, L. The Grey Generalized Verhulst Model and Its Application for Forecasting Chinese Pig Price Index. *Soft Comput.* **2020**, *24*, 4977–4990. [CrossRef]
58. Dawson, P.J. The UK Pig Cycle: A Spectral Analysis. *Br. Food J.* **2009**, *111*, 1237–1247. [CrossRef]
59. Minton, B.A.; Schrand, C. The Impact of Cash Flow Volatility on Discretionary Investment and the Costs of Debt and Equity Financing. *J. Financ. Econ.* **1999**, *54*, 423–460. [CrossRef]

60. Arellano, M.; Bover, O. Another Look at the Instrumental Variable Estimation of Error-Components Models. *J. Econom.* **1995**, *68*, 29–51. [CrossRef]
61. Bond, S.R. Dynamic Panel Data Models: A Guide to Micro Data Methods and Practice. *Port. Econ. J.* **2002**, *1*, 141–162. [CrossRef]
62. Antweiler, W.; Copeland, B.R.; Taylor, M.S. Is Free Trade Good for the Environment? *Am. Econ. Rev.* **2001**, *91*, 877–908. [CrossRef]
63. Levinson, A. Environmental Regulations and Manufacturers' Location Choices: Evidence from the Census of Manufactures. *J. Public Econ.* **1996**, *62*, 5–29. [CrossRef]
64. Van Beers, C.; Van Den Bergh, J.C. An Empirical Multi-country Analysis of the Impact of Environmental Regulations on Foreign Trade Flows. *Kyklos* **1997**, *50*, 29–46. [CrossRef]
65. Domazlicky, B.R.; Weber, W.L. Does Environmental Protection Lead to Slower Productivity Growth in the Chemical Industry? *Environ. Resour. Econ.* **2004**, *28*, 301–324. [CrossRef]
66. Busse, M. *Trade, Environmental Regulations, and the World Trade Organization: New Empirical Evidence*; World Bank Publications: Washington, DC, USA, 2004; Volume 3361.
67. Zhong, S.; Xiong, Y.; Xiang, G. Environmental Regulation Benefits for Whom? Heterogeneous Effects of the Intensity of the Environmental Regulation on Employment in China. *J. Environ. Manag.* **2021**, *281*, 111877. [CrossRef] [PubMed]
68. Chen, Z.; Kahn, M.E.; Liu, Y.; Wang, Z. The Consequences of Spatially Differentiated Water Pollution Regulation in China. *J. Environ. Econ. Manag.* **2018**, *88*, 468–485. [CrossRef]
69. Zhong, S.; Li, J.; Zhang, D. Measurement of Green Total Factor Productivity on Chinese Pig Breeding: From the Perspective of Regional Differences. *Environ. Sci. Pollut. Res.* **2022**, *29*, 27479–27495. [CrossRef]
70. da Silva, P.P.; Cerqueira, P.A. Assessing the Determinants of Household Electricity Prices in the EU: A System-GMM Panel Data Approach. *Renew. Sustain. Energy Rev.* **2017**, *73*, 1131–1137. [CrossRef]
71. Williams, B. The Direct and Indirect Role of Higher Education in Industrial Innovation: What Should We Expect? *Minerva* **1986**, *24*, 145–171. [CrossRef]
72. Tang, Z.; Shi, W. On the Logic and Process of Collaborative Innovation in Higher Vocational Education and Industrial Development. *Chin. Educ. Soc.* **2017**, *50*, 458–468. [CrossRef]
73. Wang, L.; Wang, Z.; Ma, Y. Does Environmental Regulation Promote the High-Quality Development of Manufacturing? A Quasi-Natural Experiment Based on China's Carbon Emission Trading Pilot Scheme. *Socioecon. Plann. Sci.* **2022**, *81*, 101216. [CrossRef]
74. Zhao, M.; Liu, F.; Sun, W.; Tao, X. The Relationship between Environmental Regulation and Green Total Factor Productivity in China: An Empirical Study Based on the Panel Data of 177 Cities. *Int. J. Environ. Res. Public. Health* **2020**, *17*, 5287. [CrossRef] [PubMed]