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Can Rural Industrial Integration Alleviate Agricultural Non-Point Source Pollution? Evidence from Rural China

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Abstract: Agricultural non-point pollution has become a hot topic of social concern, and the three major industries in modern rural areas gradually tend to integrate. An in-depth study of the impact of rural industrial integration on agricultural non-point pollution has important guiding significance for the realization of sustainable agricultural development. Based on the panel data of 30 provinces and municipalities in China from 2011 to 2019, this paper explores the impact of rural industrial integration on agricultural non-point source pollution and further examines the moderating effect of urbanization. The main findings are as follows. First, there is a significant inverted U-shaped relationship between rural industrial integration and agricultural non-point source pollution. At present, rural industrial integration has a tendency of alleviating agricultural non-point source pollution. Second, urbanization has a moderating effect on the impact of rural industrial integration on agricultural non-point source pollution, moving the turning point of the curve to the left, which can accelerate the arrival of the emission reduction effect of rural industrial integration. Finally, the heterogeneity test shows that compared to areas with developed economies and weak financial support, the inverted U-shaped relationship between rural industrial integration and agricultural non-point source pollution is more significant in regions with underdeveloped economies and strong financial support. The above studies enrich the relevant literature on rural industrial integration and agricultural non-point source pollution and provide a theoretical basis for the government to formulate relevant policies for promoting the development of rural industrial integration and alleviating agricultural non-point source pollution.

Keywords: industrial integration; agriculturalpollution; urbanization; nonlinear; fixed effect model

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1. Introduction

Agricultural non-point source pollution has become a worldwide pollution problem [1], affecting 30% to 50% of the Earth's surface [2]. In September 2015, the United Nations Sustainable Development Summit put forward the goal of "adopting sustainable consumption and production patterns", putting environmentally sustainable development in a key position. The 2020 World Food and Agriculture Statistical Yearbook released by the Food and Agriculture Organization of the United Nations shows that from 2000 to 2018, global pesticide use has increased by 1/3 to 4.1 million tons per year. Global chemical fertilizer use has increased to 53 million tons, i.e., on average about 121 kg of fertilizer are used per hectare of farmland. The most commonly used is nitrogen fertilizer, and there is fast growth in the use of potassium fertilizer. Global agricultural greenhouse gas emissions have increased by 16% [3]. With the intensive use of chemical fertilizers, pesticides, and plastic film, as well as the improper disposal of planting and breeding waste, nutrients such as nitrogen, phosphorus, and organic matter produced in the agricultural production process have led to increasing agricultural non-point source pollution in the ecological

environment. According to the U.S. Environmental Protection Agency (EPA), agricultural non-point source pollution is the major source of surface water pollution (e.g., rivers and lakes), accounting for two-thirds of total pollution [4]. Taken together, agricultural non-point source pollution has become an important factor threatening the security of the global ecological environment, and addressing agricultural non-point source pollution is an important way to achieve sustainable agricultural development.

As the largest developing country in the world, China's agricultural production has long adopted the traditional growth model of high input, high consumption, and high output [5], which has caused serious agricultural pollution problems. Due to technical limitations and consumption orientation, agricultural chemicals have been overused, and agricultural non-point source pollution has become one of the most important sources of water, soil, and air pollution [6], surpassing even developed countries in breadth and depth [7], posing severe challenges to sustainable agricultural development. Promoting the green and sustainable development of agriculture and accelerating the innovation and transformation of agricultural production has become an important agricultural policy orientation of the Chinese government in both the short and long runs.

The world is currently undergoing a new industrial technology revolution. In rural areas, as an advanced stage of agricultural industrialization, rural industrial integration is transforming rural industries through deep integration and spatial expansion with secondary and tertiary industries in a gradual, penetrating and cross-border manner. Rural industrial integration can not only promote the extension of the agricultural industry chain and the expansion of the multifunction of agriculture, thereby increasing farmers' employment and income levels, but also change the mode of agricultural production and reduce pollution emissions, thereby bringing both economic and ecological benefits. Then, how does rural industrial integration affect agricultural non-point source pollution? Does the effect have phasic heterogeneity and what factors can moderate it? The answers to these questions have important theoretical and practical implications for exploring a developmental strategy that adapts to the contemporary world and improves human well-being.

In the literature, much attention is paid to how to effectively prevent and control agricultural non-point source pollution. Regarding the agricultural environment, existing research mainly focuses on agricultural production agglomeration [8–10] and agricultural economic growth [11–14], which emphasizes the analysis of the effects on the agricultural environment caused by agricultural production agglomeration and the verification of the environmental Kuznetsrelationship curve (EKC) between agricultural growth and agricultural pollution. The EKC theory suggests that an increase in the level of economic development will exacerbate ecological damage within a certain range, but will improve the ecological environment after reaching a certain extent. This reminds us of the need to be aware of the possible nonlinear relationship between agricultural activities and agricultural pollution. In addition, the relationship between farmers' income growth and agricultural pollution [15,16] is also explored, and the researchers find that the sustainability of non-operating income growth is an important factor that affects agricultural non-point source pollution. Urbanization may also have an important impact on the agricultural environment, but there has not been a consensus on the impact. The induced technological change theory argues that in order to make up for the labor shortage due to urbanization, farmers often adopt chemical technology as a substitute [17], thus exacerbating agricultural non-point source pollution. Deng [18] suggests that three types of hidden environmental problems will arise in the process of urbanization: urban–rural pollution transfer, regional ecological degradation, and food chain pollution. In contrast, Chen et al. [19] argue that urbanization has promoted the adjustment of the agricultural industrial structure and promoted the intensive and large-scale production of agricultural products. Meanwhile, Lan and Xu's further research finds that urbanization can improve the environment through an emission reduction effect and a green innovation effect [20].

As agricultural modernization is carried out globally, rural industrial integration, as an important component and dimension of agricultural modernization, has gradually attracted widespread attention from academics. Due to the different characteristics of agricultural production and historical traditions, countries around the world have formed their own distinctive development models in rural industrial integration. The Japanese scholar Naratomi Imamura first proposed the concept of "six industries" [21]. In Korea, the exploration of the six industrialization paths was started by drawing on the experience of Japanese agricultural development [22]. In the United States, the emergence of new industrial forms such as digital agriculture has provided a great impetus for its development [23]. At the same time, China fully refers to and draws on the international experience of rural industrial integration in the countryside, gives full play to its resource advantages according to local conditions, and focuses on developing advantageous industries and extending agricultural value chains to help rural revitalization. Based on the rapid development of rural industrial integration, how to assess the socio-economic impact of industrial integration is an important topic. In summary, the current literature on rural industrial integration focuses on exploring its economic effects. A part of the literature focuses on the economic effects of rural industrial integration. Early studies on industrial integration focused on the communication industry. For example, Freeman et al. [24] argue that industrial integration helps to achieve economies of scope, but Cao et al. [25] and Amir et al. [26] find that industrial integration also has a polarization effect and thus can harm certain disadvantaged industries. Specifically for rural industrial integration, there is an academic consensus on the poverty reduction effects of industrial integration. According to Tu [27], industrial poverty alleviation is a fundamental strategy to achieve stable poverty alleviation for the poor, and this "blood-making" industrial poverty alleviation process is mainly dependent on the mechanisms of rural economic growth and urbanization development [28], rural digitalization penetration and rural education investment [29]. Similarly, industrial integration also has a significant positive impact on agricultural growth, which can enhance agricultural economic resilience [30] and raise farmers' income [31], thus steadily achieving rural revitalization.

Another part of the literature focuses on the economic effects of agricultural industrialized economic organizations. Through the management mode of agricultural cooperatives, rural primary, secondary and tertiary industries are deeply integrated [32]. Some evidence from international sources suggests that participation in agricultural cooperatives is beneficial to the welfare of farmers [33–36]. However, some studies have also shown that agricultural cooperatives can have adverse effects on organizational members, such as the inability to flexibly meet farmers' daily needs [37] and low levels of productivity and profitability [38], possibly due to differences in the indicators considered.

As the above studies show, the economic effects of rural industrial integration have attracted the attention of many scholars. However, as an important form of change in rural industries, rural industrial integration will certainly have an impact on the agricultural ecological environment that cannot be ignored. However, most of the previous studies have only focused on its economic effects, but ignored its potential ecological effects. Related to this topic, Wang et al. [39] take China as an example to empirically test the effect of rural industrial integration development on green total factor productivity. Luo et al. [40] find that rural industrial integration can restrain pollution in agricultural production. The application of digital technology in agriculture enhances the transparency of agricultural production and enables the government to target sustainable agricultural policies and thus achieve emission reduction targets [41].

Overall, the existing literature has provided valuable insights for this paper. However, the research has neither explored the possible nonlinear relationship between rural industrial integration and agricultural non-point source pollution, nor has it clarified the relationship between the two and the underlying mechanism. In view of this, this paper aims to investigate the nonlinear effect of rural industrial integration on agricultural non-point source pollution and further examine the mechanism and heterogeneity of the effect.

Compared to the existing literature, this paper makes the following contributions. First, this paper assembles panel data from 30 provinces in China between 2011 and 2019 to conduct an empirical analysis, using the fixed effect model to test the relationship between rural industrial integration and agricultural non-point source pollution, which fills the gap in the existing literature. Second, from a perspective of urbanization, this paper investigates the mechanism through which rural industrial integration influences agricultural non-point source pollution, which enriches the relevant literature on agricultural non-point source pollution. Also, it enriches the literature on rural industrial integration and urbanization, enhancing the policy effectiveness of rural industrial integration development in reducing agricultural non-point source pollution.

2. Theoretical Analysis and Research Hypothesis

2.1. The Impact of Rural Industrial Integration on Agricultural Non-Point Source Pollution

Rural industrial integration can affect agricultural non-point source pollution through two contrasting effects: the pollution effect and emission reduction effect. The first is the pollution effect. With increasing rural industrial integration, the adoption of modern technologies will inevitably lead to the expansion of agricultural production. This can aggravate agricultural non-point source pollution, as China's agricultural production still highly depends on agrochemical inputs now and will still in years to come [8], while rural environmental infrastructure is insufficient [42], and it is difficult to effectively handle the overuse of agrochemicals. The second is the emission reduction effect. The theory of economies of scale suggests that a large-scale and intensive operation of agriculture can improve the utilization rate of resources and reduce the intensity of inputs (e.g., pesticides and chemical fertilizers) while maintaining outputs, thus alleviating pollution. In addition, rural industrial integration can improve rural human capital and promote agricultural technology progress, prompting producers to change the traditional extensive mode of production [40], thereby alleviating agricultural non-point source pollution. Given the pollution and emission reduction effects, there can be a nonlinear relationship between rural industrial integration and non-point source pollution. This paper hypothesizes that in the initial stage of rural industrial integration, the pollution effect induced by production expansion may exceed the emission reduction effect, and when rural industrial integration advances to a certain degree, the emission reduction effect associated with economies of scale will become salient.

Figure 1 summarizes the impact of rural industrial integration on agricultural non-point source pollution, which motivates the following hypothesis.

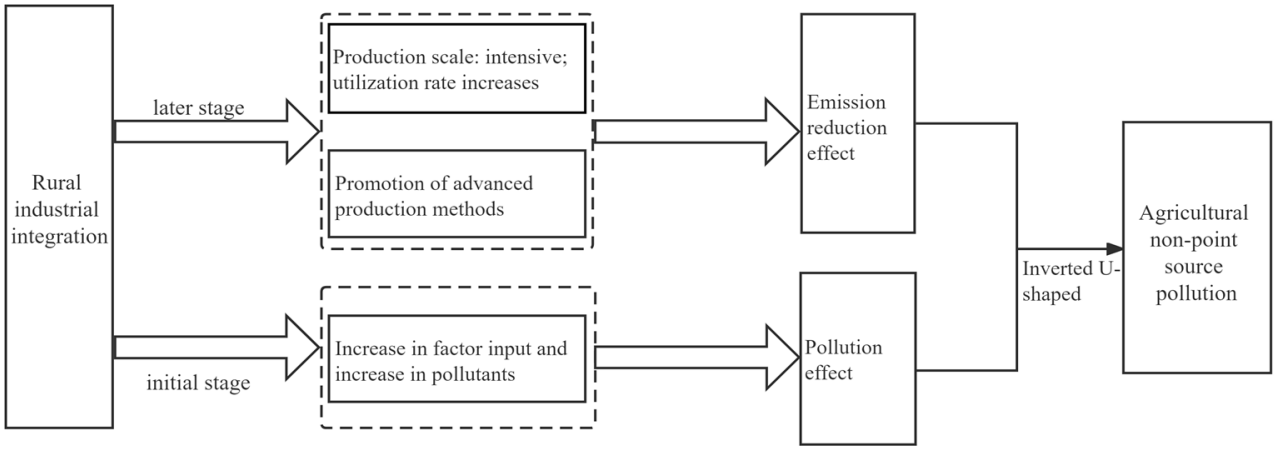

Figure 1. Relationship between rural industrial integration and agricultural non-point source pollution.

Hypothesis 1 (H1). *Rural industrial integration and agricultural non-point source pollution have an inverted U-shaped relationship. With the development of rural industrial integration, agricultural non-point source pollution first increases and then decreases.*

2.2. Moderating Effect of Urbanization on the Relationship between Rural Industrial Integration and Agricultural Non-Point Source Pollution

The moderating effect of urbanization on the impact of rural industrial integration on agricultural non-point source pollution is primarily due to the following two forces. On the one hand, urbanization may help contain non-point source pollution, as it can (1) spread technologies to rural areas through urban growth poles, providing the material basis and technological support for sustainable agricultural development [43] and improving the capacity of agricultural pollution control; (2) shift rural surplus labor to non-agricultural sectors [44], thus improving agricultural production efficiency and promoting the realization of large-scale agricultural production; and (3) enhance farmers' awareness of environmental protection and improve the infrastructure construction of rural sewage discharge and pollution control [45]. On the other hand, with the continuous advancement of urbanization, urbanization is more likely to lead to flows of resources from rural areas to urban areas [46] and thus result in the hollowing out of agriculture [47], which can hinder rural industrial integration. In addition, as a consequence of urbanization, the sharp reduction in agricultural arable land can increase agricultural production costs [48], forcing agricultural producers to choose low-cost but high-pollution production technologies, which limits the efficiency of the emission reduction effect of rural industrial integration.

Therefore, this paper proposes that with the improvement of urbanization, agricultural non-point source pollution can be alleviated to some extent in the initial stage of rural industrial integration. However, when rural industrial integration develops to some degree, its emission reduction effect will be limited by the progress of urbanization. This is summarized by hypothesis 2 below.

Hypothesis 2 (H2). *Urbanization has a moderating effect on the relationship between rural industrial integration and agricultural non-point source pollution. With a higher urbanization level, the inverted U-shaped curve of the relationship between rural industrial integration and agricultural non-point source pollution tends to be flatter.*

3. Methods and Data

3.1. Model Construction

In order to test the relationship between rural industrial integration and agricultural non-point source pollution, this paper uses the following regression model:

$$AP_{it} = \alpha_0 + \alpha_1 AC_{it} + \alpha_2 (AC_{it})^2 + \alpha_3 Controls_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (1)$$

In Equation (1), i indexes provinces, and t indexes years. AP_{it} is the agricultural non-point source pollution degree of province i in year t, and AC_{it} is the level of rural industrial integration. $Controls_{it}$ includes a set of control variables. μ_i is the province fixed effect, and δ_t is the year fixed effect. ε_{it} is the error term. Furthermore, in order to examine the nonlinear impact of rural industrial integration on agricultural non-point source pollution, Equation (1) includes the quadratic term of the level of rural industrial integration, (AC_{it}^2).

3.2. Variable Settings

3.2.1. Explained Variable

The explained variable is agricultural non-point source pollution (AP). Compared with point source pollution, agricultural non-point source pollution is more widespread, so there have not been very accurate measurements. In this paper, following Du et al. [49], we construct a comprehensive evaluation index for agricultural non-point source pollution,

which is a weighted average of an area's three indicators: (1) the pesticide application amount (AP-pest), (2) chemical fertilizer application amount (AP-fert), and (3) agricultural plastic film usage amount (AP-plas). We introduce the construction procedure below.

In order to unify the units of indicators, this paper standardizes the indicators as follows:

$$\text{Positive indicator } v_{tij} = \left(x_{tij} - \min x_{tij}\right) / \left(\max x_{tij} - \min x_{tij}\right) \tag{2}$$

$$\text{Negative indicator } v_{tij} = \left(\max x_{tij} - x_{tij}\right) / \left(\max x_{tij} - \min x_{tij}\right) \tag{3}$$

x_{tij} is the value of indicator j of province i in year t. v_{tij} is the standardized value. Furthermore, following Hao et al. [30], this paper uses an entropy method to determine the weight that each indicator receives in constructing the comprehensive evaluation index of AP_{it}. Specifically, let T, M, and N be the maximum values of t, i, and j in the sample, respectively.

$$\text{① Conversion : } P_{tij} = v_{tij} / \sum_{t=1}^{T} \sum_{i=1}^{M} v_{tij} \tag{4}$$

$$\text{② Calculation of index information entropy and information utility value : } e_j = -K \sum_{t=1}^{T} \sum_{i=1}^{M} \left(P_{tij} \times \ln P_{tij}\right),\ K = 1/\ln(T \times M),\ d_j = 1 - e_j \tag{5}$$

$$\text{③ Calculate the weight for each indicator : } w_j = d_j / \sum_{j=1}^{N} d_j \tag{6}$$

$$\text{④ Calculate the comprehensive evaluation index : } S_{ti} = \sum_{j=1}^{N} \left(w_j \times v_{tij}\right) \tag{7}$$

Table 1 presents the weight placed on each indicator.

Table 1. Agricultural non-point source pollution index system.

	Primary Indicators	Secondary Indicators and Their Weights	Unit	Indicator Properties	Data Sources
Agricultural non-point source pollution	Total pesticide pollution (AP-pest)	Pesticide application rate, 0.338	tons	Positive	"China Rural Statistical Yearbook"
	Total fertilizer pollution (AP-fert)	Scale amount of fertilizer application, 0.316	tons	Positive	"China Rural Statistical Yearbook"
	The total amount of agricultural plastic film pollution (AP-plas)	Agricultural plastic film usage, 0.346	tons	Positive	"China Rural Statistical Yearbook"

3.2.2. Core Explanatory Variable

The core explanatory variable is the level of rural industrial integration development (AC). Since rural industrial integration is a concept encompassing many aspects, it cannot be accurately evaluated with a single indicator. Most studies use a comprehensive index to measure rural industrial integration. To construct the comprehensive index for AC, drawing upon the existing research results [28,50,51], this paper considers six indicators of four categories: (1) the extension of the agricultural industry chain, (2) the cultivation of new agricultural formats, (3) the integrated development of the agricultural service industry, and (4) the improvement of the interest linkage mechanism. The indicators are listed in Table 2. When calculating the comprehensive evaluation index, the entropy method is also used to determine the weights.

Table 2. Comprehensive evaluation index system of rural industrial integration development level.

	Level 1 Indicators	Secondary Indicators and Their Weights	Unit	Indicator Properties	Data Sources
Rural Industrial Integration	Agricultural industry chain extension 0.303	Total power of primary processing machinery of agricultural products/total power of agricultural machinery, 0.215	%	Positive	"China Agricultural Machinery Industry Yearbook"
		Gross output value of primary industry/number of rural population, 0.088	100 million CNY/10,000 people	Positive	Provincial Statistical Yearbooks, China Statistical Yearbook, China Population and Employment Statistical Yearbook
	Cultivation of new agricultural formats 0.362	Area of facility agriculture/arable land area, 0.362	%	Positive	National Greenhouse Data System, China Economic Network Statistical Database
	Integrated development of agricultural service industry 0.188	Gross output value of agriculture, forestry, animal husbandry and fishery services/gross output value of primary industry, 0.139	%	Positive	Provincial Statistical Yearbooks, "China Statistical Yearbook"
		Average number of mobile phones per household in rural households, 0.049	department	Positive	Provincial Statistical Yearbooks, "China Statistical Yearbook"
	The benefit linkage mechanism is perfected 0.147	Number of farmers' professional cooperatives per 10,000 people in rural areas, 0.147	person/10,000 people	Positive	Statistical Annual Report on Rural Operations and Management in China

3.2.3. Control Variables

In order to control the influences of other factors on agricultural non-point source pollution, this paper includes a range of control variables in light of the existing research [7,14,52–55], including the (1) rural consumption level (lnconsume), i.e., per capita consumption in rural areas (unit: CNY/person, in log); (2) rural fixed asset investment (lninvest), i.e., the rural fixed asset investment (unit: 100 million CNY, in log); (3) the level of openness to the outside world (lnopen), i.e., the share of trade (exports and imports) in provincial GDP (unit: %, in log); (4) education level (lnedu), i.e., the average years of schooling for rural residents above 6 years old (the formula is (illiteracy $\times$ 0 + primary school education $\times$ 6 + junior high school education $\times$ 9 + high school and technical secondary school $\times$ 12 + junior college and above $\times$ 16)/total rural population aged 6 and over; unit: year/person, in log); (5) the income gap between urban and rural areas (lnuig), i.e., the ratio of per capita disposable income of urban and rural residents (unit: %, in log); (6) rural electricity consumption (lnelec) (unit: 100 million kWh, in log); (7) government environmental control (lngov), which is proxied by expenses from industrial pollution control (unit: 10,000 CNY, in log); (8) the degree of the disaster of agricultural products (disaster), i.e., the proportion of affected farmland (unit: %).

3.2.4. Moderating Variable

The moderating variable is the level of urbanization (urb). Population urbanization and land urbanization are two important aspects of urbanization [56]. In light of this, this paper examines the moderating effects of population urbanization and land urbanization on the relationship between rural industrial integration and agricultural non-point source pollution. Population urbanization is measured by the ratio of urban population to total population, while land urbanization is measured by the ratio of urban built-up areas to urban areas, following Gao et al. [56].

3.3. Data Source

As a typical agricultural country, China's long-term crude agricultural growth model has caused great damage to the agricultural environment. At the same time, China is still a developing country with relatively slow agricultural economic development, which is representative in serving as a test of the nonlinear relationship between rural industrial integration and agricultural non-point source pollution. In view of this, this paper uses panel data from 30 provinces (municipalities, and autonomous regions) in China between

2011 and 2019 for analysis. Hong Kong, Macao, Taiwan, and Tibet are not included due to the lack of data. Tables 1 and 2 have listed the data sources of the indicators used for measuring agricultural non-point source pollution and rural industrial integration. Control variables come from "China Rural Statistical Yearbook", "China Environmental Statistical Yearbook", "China Population and Employment Statistical Yearbook", "China Statistical Yearbook", and provincial statistical yearbooks. Some missing values are filled in using imputations via the linear interpolation method and the mean method. Table 3 displays the descriptive statistics. It can be seen from Table 3 that the average value of the rural industrial integration level is only 0.245, indicating that the development level is low, and there are large differences across regions. Regarding agricultural non-point source pollution, the minimum and maximum values are 0.003 and 0.878, respectively, reflecting large differences in the use of pesticides, fertilizers and agricultural plastic films across regions.

Table 3. Descriptive statistics.

Variable Name	Sample Size	Average	Median	Standard Deviation	Minimum Value	Maximum Value
AP	270	0.283	0.292	0.197	0.003	0.878
AC	270	0.245	0.238	0.080	0.083	0.459
urb	270	0.576	0.556	0.122	0.368	0.893
lnconsume	270	9.103	9.120	0.386	8.269	9.969
lnelec	270	4.853	2.058	1.327	1.504	7.543
lninvest	270	5.402	5.716	1.140	1.197	6.865
lngov	270	11.950	4.684	0.965	8.897	13.94
disaster	270	0.154	12.020	0.115	0.012	0.574
lnuig	270	0.950	0.127	0.142	0.616	1.279
lnopen	270	4.842	0.942	1.116	2.055	6.690
lnedu	270	2.047	4.926	0.077	1.816	2.254

4. Results

Before the empirical analysis, to ensure the validity of the results, the following restrictions are imposed. First, the sample is winsorized 1% level at each tail to avoid the influence of outliers. Second, to avoid estimation results being driven by possible multicollinearity, the core explanatory and moderator variables are centralized before constructing the interaction item. The variance inflation factor (VIF) test shows that the average value of VIF is about 2.9, and the VIF values of all variables are less than 10, indicating that there is no severe multicollinearity problem. Third, considering that the unit of analysis is at the provincial level, in this paper, robust standard errors are clustered at the provincial level to address heteroscedasticity and serial correlation in the error term.

4.1. Benchmark Regression Results

A Hausman test is performed for Equation (1) to discriminate between fixed effect and random effect models. The results show that the null hypothesis is rejected at the 1% significance level, indicating that it is more appropriate to use the fixed effect model. The benchmark regression results are reported in Table 4 (in this paper, the natural logarithm of the use of pesticides, fertilizers and agricultural film is estimated. Due to the use of pesticides and agricultural film, some variable values are less than 1. In order to avoid the negative impact on the model estimation after taking the natural logarithm, the natural logarithm is taken after adding 1 to the original value of the variable).

Table 4 reports the baseline regression results. Column (1) is the regression result of only including rural industrial integration. It shows that the effect of rural industrial integration is not statistically significant. Column (2) adds the quadratic term of rural industrial integration based on Column (1). The results show that the coefficient on the linear term of rural industrial integration is significantly positive at the 10% level, and

the coefficient on the quadratic term is significantly negative at the 5% level. According to Haans et al. [57], there is an inverted U-shaped relationship between rural industrial integration and agricultural non-point source pollution, as three conditions for the inverted U-shaped relationship are met. First, the coefficient on the quadratic item of rural industrial integration, α_2, is significantly less than 0. Second, the turning point value of the inverted U-shaped curve is about 0.2797, which is within the sample range of rural industrial integration, 0.083–0.459. Finally, the slope of the curve with respect to rural industrial integration (AC) is 0.678–2 × 1.212 × AC. When AC takes the minimum value, the slope is positive; when AC takes the maximum value, the slope is negative. Therefore, there is a significant inverted U-shaped relationship between rural industrial integration and agricultural non-point source pollution, indicating the existence of both pollution and emission reduction effects of rural industrial integration. At the early stage of rural industrial integration development, the pollution effect is greater than the emission reduction effect, leading to the increase in agricultural non-point source pollution; in the later stage of rural industrial integration development, the emission reduction effect gradually becomes salient, which effectively reduces agricultural non-point source pollution. Thus, H1 is verified. Columns (3)–(5) of Table 4 further examine the inverted U-shaped relationship between rural industrial integration and the three major pollution sources, i.e., pesticides, fertilizers, and agricultural plastic films. Reassuringly, the results show significant inverted U-shaped relationships between rural industrial integration and three major pollution sources.

Table 4. Benchmark regression results.

Variable	(1)	(2)	(3)	(4)	(5)
AC	−0.096	0.678 *	2.022 **	3.732 **	2.917 ***
	(−1.13)	(2.03)	(2.39)	(2.72)	(2.78)
AC^2		−1.212 **	−3.267 **	−5.388 ***	−3.946 **
		(−2.35)	(−2.55)	(−2.86)	(−2.58)
lnconsume	−0.055	−0.095 *	−0.328 **	0.028	0.059
	(−0.96)	(−1.72)	(−2.39)	(0.20)	(0.42)
lnedu	0.190 *	0.211 **	0.288	−0.119	0.271
	(1.89)	(2.22)	(1.06)	(−0.44)	(1.22)
disaster	0.018	0.011	0.071	0.020	−0.019
	(1.17)	(0.96)	(1.43)	(0.56)	(−0.50)
lninvest	0.006	0.005	−0.020	−0.048	0.063
	(0.44)	(0.41)	(−0.52)	(−1.09)	(1.40)
lnelec	0.017	0.019	−0.008	0.026	0.058
	(0.97)	(1.37)	(−0.22)	(0.58)	(1.64)
lngov	−0.010 ***	−0.011 ***	−0.020	−0.026 **	−0.025 **
	(−2.89)	(−3.13)	(−1.51)	(−2.44)	(−2.23)
lnopen	0.009	0.003	0.024	0.013	−0.033
	(0.60)	(0.21)	(0.79)	(0.40)	(−0.96)
lnuig	0.080	0.051	−0.081	−0.239	−0.065
	(0.56)	(0.45)	(−0.29)	(−0.55)	(−0.21)
_cons	0.261	0.540	3.979 ***	4.982 ***	0.399
	(0.40)	(0.93)	(2.95)	(4.43)	(0.37)
year effect	yes	yes	yes	yes	yes
province effect	yes	yes	yes	yes	yes
model class	fixed effect	fixed effect	fixed effect	fixed effect	fixed effect
Hausman test	71.158	77.442	89.373	109.432	61.126
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
N	270	270	270	270	270
adj. R^2	0.377	0.458	0.564	0.485	0.418

Note: The t values of each coefficient are in parentheses; *, **, and *** show significance levels of 10%, 5% and 1%, respectively; the accompanying probability of the Hausman test is in the square brackets.

From the perspective of the overall sample, the turning point value of the inverted U-shaped curve estimated above is about 0.2797. Referring to the descriptive statistical results in Table 3, it can be seen that the average and median of rural industrial integration levels are 0.245 and 0.238, respectively, which are very close to the turning point. This suggests that nearly half of Chinese provinces' rural industrial integration levels have passed the turning point, and so can exert a pollution-reducing effect. For the rest of the

provinces, its possible side effects should be taken into account while accelerating rural industrial integration.

It is also interesting to examine the impacts of control variables. Rural consumption and government environmental control are significantly negative. One possible reason is that when farmers' consumption capacity increases, they will pursue the consumption of high-quality products, which will increase the production of green agricultural products [53] and thus indirectly reduce agricultural non-point source pollution. An increase in the intensity of government environmental control can effectively regulate agricultural production and directly inhibit agricultural non-point source pollution. However, the improvement of farmers' education level is not conducive to reducing agricultural non-point source pollution. One likely reason is that more educated farmers are more likely to abandon traditional farming approaches, which accelerates the use of fossil energy in agricultural production [54]. The impact of other control variables on agricultural non-point source pollution is not salient.

4.2. Robustness Check

4.2.1. Alternative Measurements of Explanatory Variables

Previous regression analysis revealed an inverted U-shaped relationship between rural industrial integration and agricultural non-point source pollution. Meanwhile, the impact of other explanatory variables on agricultural non-point source pollution was discussed, and the conclusions obtained are largely in line with theoretical expectations. Further, this paper conducts a robustness test by using alternative measures of explanatory variables to see whether or not there is still an inverted U-shaped relationship between rural industrial integration and agricultural non-point source pollution. Specifically, following Chen et al. [58], the level of rural industrial integration is recalculated using the dimensionless processing method. The new normalization formula is as follows:

$$\text{Positive indicator } v_{tij} = x_{tij} / \max x_{tij} \quad (8)$$

$$\text{Negative indicator } v_{tij} = \min x_{tij} / x_{tij} \quad (9)$$

The regression results are shown in Column (1) of Table 5. The regression results show that after changing the calculation method of the core explanatory variables, the coefficients on the linear and quadratic terms of rural industrial integration are both significant at the 10% level, and the symbols are consistent with the baseline regression, which shows the robustness of the regression results.

Table 5. Robustness test results.

	(1) Replace the Core Explanatory Variables	(2) Eliminate Municipalities Directly under the Central Government	(3) 2SLS
AC	0.420 *	0.600 *	0.716 **
	(1.71)	(1.94)	(1.97)
AC^2	−0.717 *	−1.183 **	−1.341 **
	(−1.98)	(−2.48)	(−2.36)
control variable	control	control	control
constant term	0.407	1.082 *	
	(0.65)	(1.78)	
year effect	yes	yes	yes
province effect	yes	yes	yes
N	270	234	240
adj. R^2	0.405	0.562	0.421
Kleibergen-Paap RK L			7.16 ***
			[0.0075]
Cragg-Donald Wald F			67.75

Note: The t values of each coefficient are in parentheses; *, **, and *** show significance levels of 10%, 5% and 1%, respectively; the accompanying probabilities of the instrumental variable underidentification test are in the square brackets.

4.2.2. Excluding Municipalities Directly under the Central Government

China has four municipalities directly under the central government in terms of administrative divisions, which can have advantages in economy, politics, and location, and are different from other provinces in terms of policy orientation. To ensure that the results are not driven by these municipalities, this paper excludes them from the sample and re-examines the impact of rural industrial integration on agricultural non-point source pollution. Column (2) in Table 5 shows the estimation results of the benchmark regression model after excluding the samples of the four municipalities directly under the Central Government: Beijing, Tianjin, Shanghai, and Chongqing. The results show that the coefficient on the linear term of AC is significantly positive, and the coefficient on the quadratic term is significantly negative. Thus, the inverted U-shaped relationship still holds.

4.2.3. Estimation of 2SLS

To address potential endogeneity bias due to reverse causality, this paper follows Lin et al. [59] and uses one-period lagged rural industrial integration and its quadratic term as instrumental variables for current rural industrial integration. Two-stage least squares (2SLS) estimation is conducted. Column (3) of Table 5 reports the 2SLS results using the one-period lagged core explanatory variable and its quadratic term as instrumental variables. The Kleibergen–Paap rk LM statistic is significant at the 1% level, and the Cragg–Donald Wald F statistic is 67.75, which is greater than the critical value (7.03) of the Stock–Yogo weak instrumental variable test at the 10% level, indicating that there is no insufficient identification and weak instrumental variable problems. The selection of the instrumental variables is reasonable; at the same time, because the number of instrumental variables and endogenous explanatory variables is equal, the model is just identified, and there is no problem of over-identification. After considering the impact of endogeneity on the regression results of this paper, the inverted U-shaped relationship between rural industrial integration and agricultural non-point source pollution is still significant, which further verifies the robustness of the previous regression results.

4.3. Moderating Effect Analysis

Based on the previous theoretical analysis, in order to test the moderating role of urbanization in the relationship between rural industrial integration and agricultural non-point source pollution, this paper estimates the following model:

$$AP_{it} = \alpha_0 + \alpha_1 AC_{it} + \alpha_2 (AC_{it})^2 + \alpha_3 AC_{it} \times urb_{it} + \alpha_4 (AC_{it})^2 \times urb_{it} + \alpha_5 urb_{it} + \alpha_6 Controls_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (10)$$

This model follows Haans et al. [57] to analyze the slope change of the curve and the movement of the turning point. On the one hand, if the coefficient on $(AC_{it})^2 \times urb_{it}$, i.e., α_4, is significantly positive, urbanization can weaken the inverted U-shaped curve; if α_4 is negative, urbanization can strengthen the inverted U-shaped curve. On the other hand, if the value of $\alpha_1 \times \alpha_4 - \alpha_2 \times \alpha_3$ is positive, urbanization can move the turning point of the curve to the right, and if it is negative, it can move the turning point of the curve to the left. The specific estimation results are shown in Table 6, in which (1)–(3) are listed as the regression results of population urbanization, and (4)–(6) are listed as the regression results of land urbanization. It can be seen from Table 6 that after adding the interaction term between rural industrial integration and its square term and the urbanization level, the coefficients of AC and AC^2 have no significant change compared with to values in Table 4, that is, the relationship between rural industrial integration and agricultural non-point source pollution. There is still an inverted U-shaped relationship. It can be seen from Columns (2) and (5) that the coefficient on the interaction term between rural industrial integration and urbanization level is not significant, indicating that the level of urbanization is not a simple linear adjustment between rural industrial integration and agricultural non-point source pollution. From Columns (3) and (6), it can be seen that the coefficient of

the interaction item of rural industrial integration and urbanization level is significantly negative at the 10% level, and the coefficients of the interaction item of the square item of rural industrial integration and urbanization level are both significantly positive, indicating that urbanization can weaken the promoting effect in the first half of the inverted U-shaped curve and the inhibiting effect in the second half. The increase in the level of urbanization will flatten the inverted U-shaped relationship curve between rural industrial integration and agricultural non-point source pollution. H2 is verified. The possible reasons are that before the inflection point, with the improvement of the urbanization level, the absorption of rural surplus labor by non-agricultural industries is conducive to the realization of large-scale agricultural production. At the same time, cities can also spread technology to rural areas, improving pollution control in rural areas, which has weakened the promoting effect of rural industrial integration on pollution in the first half. After the integration level passes the turning point, with the improvement of urbanization, the loss of a large number of high-quality laborers will become the main problem restricting rural development. Insufficient power will be detrimental to the further development of rural industrial integration. At the same time, the rise in production costs will make agricultural producers more inclined to use more polluting methods for production, thus weakening the inhibiting effect of industrial integration on pollution in the second half.

Table 6. Moderating effect analysis results.

	(1)	(2)	(3)	(4)	(5)	(6)
AC	0.673 *	0.717 **	0.611 *	0.669 *	0.632 *	0.575 *
	(2.01)	(2.05)	(1.83)	(2.02)	(1.86)	(1.72)
AC^2	−1.208 **	−1.308 **	−1.241 **	−1.175 **	−1.110 **	−1.077 *
	(−2.34)	(−2.25)	(−2.24)	(−2.31)	(−2.07)	(−2.04)
urb	0.019	0.070	−0.417	−2.011 **	−1.936 **	−3.167 ***
	(0.09)	(0.29)	(−1.42)	(−2.10)	(−2.08)	(−2.88)
AC × urb		0.217	−3.918 *		−0.734	−14.762 *
		(0.43)	(−1.87)		(−0.42)	(−1.88)
AC^2 × urb			7.148 **			25.287 *
			(2.11)			(1.88)
control variable	control	control	control	control	control	control
constant term	0.537	0.500	0.864	0.597	0.613	0.620
	(0.93)	(0.83)	(1.55)	(1.19)	(1.24)	(1.28)
year effect	yes	yes	yes	yes	yes	yes
province effect	yes	yes	yes	yes	yes	yes
N	270	270	270	270	270	270
adj. R^2	0.456	0.455	0.498	0.496	0.494	0.522

Note: The t values of each coefficient are in parentheses; *, **, and *** show significance levels of 10%, 5% and 1%, respectively.

In addition, by calculating $\alpha_1 \times \alpha_4 - \alpha_2 \times \alpha_3$ in Table 6, its values are 0.4948 and −1.3586, respectively, indicating that the turning point of the curve will move to the left. That is, as the level of urbanization increases, the turning point of the inverted U-shaped curve of rural industrial integration and agricultural non-point source pollution moves toward a direction where the development level of rural industrial integration is relatively small, indicating that the advancement of urbanization can partially offset the promoting effect of rural industrial integration on agricultural non-point source pollution. Furthermore, the integration of rural industries can provide early "feedback" on agricultural non-point source pollution, which is conducive to reducing agricultural non-point source pollution.

4.4. Heterogeneity Test

4.4.1. Regional Heterogeneity

Considering China's large regional heterogeneity in resource endowments and economic development levels, there can be significant differences in the levels of rural in-

dustrial integration between regions. Generally speaking, the level of rural industrial integration and development in economically developed areas is also relatively high. On the contrary, the level of rural industrial integration is relatively low in underdeveloped areas. Then, is there any regional difference in the impact of rural industrial integration on agricultural non-point source pollution? In this paper, according to the per capita GDP level of each province, the full sample is divided into two sub-samples of economically developed regions and economically underdeveloped regions according to the average value to investigate whether or not there is regional heterogeneity in the impact of rural industrial integration on agricultural non-point source pollution. The regressions use the two-way fixed effect model, and the results are in Table 7 (1)–(2). From the regression results of the two sub-samples, it can be seen that rural industrial integration exhibits a "tail effect", that is, the regression results in economically underdeveloped areas are basically consistent with those of the full sample, but not significant in economically developed areas. One explanation is that the integration of rural industries in economically developed areas started earlier, and the level of development is relatively high. Given that the starting year of the sample in this paper is 2011, the development level of rural industrial integration may have passed the turning point (the author empirically found that in economically developed areas, there is a significant negative relationship between rural industrial integration and agricultural non-point source pollution, but this relationship is not significant in economically underdeveloped areas, which is consistent with the primary term coefficient of rural industrial integration in Table 4, which is negative but not significant from echoes), so the expansion of the agricultural production scale and the adoption of advanced production methods have brought into play the emission reduction effect, which has begun to inhibit agricultural non-point source pollution, while in economically underdeveloped areas, the integrated development of rural industries is relatively backward, and it will take longer to reach the inflection point. Therefore, there is an inverted U-shaped relationship within the sample interval.

Table 7. Heterogeneity test results.

	(1) Economically Underdeveloped Areas	(2) Economically Developed Areas	(3) High Financial Support for Agriculture	(4) Low Financial Support for Agriculture
AC	0.701 *	−0.101	0.714 **	0.697
	(2.06)	(−0.34)	(2.11)	(1.22)
AC^2	−1.137 **	−0.095	−1.289 **	−1.197
	(−2.22)	(−0.21)	(−2.69)	(−1.39)
control variable	control	control	control	control
constant term	1.142 ***	0.686	1.502 ***	0.219
	(3.07)	(1.34)	(3.48)	(0.28)
year effect	yes	yes	yes	yes
province effect	yes	yes	yes	yes
N	173	97	120	150
adj. R^2	0.511	0.705	0.574	0.452

Note: The t values of each coefficient are in parentheses; *, **, and *** show significance levels of 10%, 5% and 1%, respectively.

4.4.2. Heterogeneity of Financial Support to Agriculture

In addition, the intensity of local government financial support for agriculture is also an important factor affecting the development of rural industrial integration [60]. Based on this, this paper takes the proportion of fiscal support to agriculture in the total expenditure as the basis for grouping, divides the fiscal support to agriculture into two sub-samples according to the average value, and investigates the heterogeneity of fiscal support to agriculture. From Columns (3) and (4) of Table 7, it can be seen that there is a significant inverted U-shaped relationship between rural industrial integration and agricultural non-point source pollution under high financial support to agriculture, while the relationship between the two sides is not obvious under low financial support to agriculture. This shows

that the impact of rural industrial integration on agricultural non-point source pollution does have heterogeneity under different levels of financial support. Therefore, in order to further alleviate agricultural non-point source pollution, the government still needs to increase its emphasis on agriculture.

5. Discussion

In this paper, we investigate the impact of rural industrial integration on agricultural non-point source pollution using macro-provincial data from China. We not only directly examine the nonlinear relationship between rural industrial integration and agricultural non-point source pollution, but also specifically analyze the heterogeneity and possible mechanisms of the effect and discuss possible endogeneity issues.

The results of the study suggest that the development of rural industrial integration in China is significantly associated with the degree of agricultural non-point source pollution. Specifically, rural industrial integration first exacerbates pollution and then alleviates it after reaching a certain level. This is inconsistent with the findings of Wang et al. [39], Luo et al. [40], and Freeman et al. [41], whose studies directly or indirectly show a negative relationship between rural industrial integration and agricultural pollution. In this regard, we provide more possibilities between the two, and we argue that an inverted U-shaped EKC relationship is presented between rural industrial integration and agricultural non-point source pollution, which enriches the environmental Kuznets theory about the nonlinear impact of economic activities on the ecological environment to a certain extent. For the explanation of the relationship between the two, they argue that rural industrial integration can alleviate agricultural pollution by promoting green technological progress and achieving a scale effect, which is consistent with our explanation of the second half of the inverted U-shaped curve. In addition, we also discuss the possible increase in pollution that may be brought on by the expansion of the production scale due to the development of rural industrial integration in the first place. This paper contributes to a deeper understanding of the relationship between rural development and agricultural production in developing countries. Therefore, in developing countries where agricultural technology is not yet developed, it is necessary to take measures to regulate the production behavior of farmers and thus control agricultural pollution.

We also find that the above inverted U-shaped relationship is not significant when the sample is limited to economically developed areas and low financial support areas. The possible reasons for this phenomenon are as follows. First, since economically developed areas have better agricultural infrastructure, especially in terms of agricultural technology and equipment, compared with economically underdeveloped areas, developed areas have a better agricultural development environment, and rural industrial integration can give better realize the green production effect. Second, low financial support areas may be limited by financial and agricultural resources, and these factors may reduce the impact of industrial integration on the agricultural ecological environment.

For the mechanism of rural industrial integration affecting agricultural non-point source pollution, we examine the moderating effect of urbanization in the relationship between the two, which includes population urbanization and land urbanization. We find that both population urbanization and land urbanization have a moderating effect in the relationship between rural industrial integration and agricultural non-point source pollution, and make rural industrial integration have an inhibiting effect on agricultural non-point source pollution in advance. Gu et al. [61] point out that urbanization is an effective way to promote the large-scale management of agricultural land and then achieve green agricultural development, and our study also supports this view. Therefore, according to our study, urbanization is an important mechanism for rural industrial integration to affect agricultural non-point source pollution.

6. Conclusions and Recommendations

In summary, the development level of rural industrial integration and the agricultural ecological environment in China are significantly correlated. The development of urbanization acts as an influence mechanism. When it comes to economically developed areas and low financial support areas for agriculture, the effect is relatively insignificant, which verifies the two hypotheses proposed in the previous paper, which are that first, rural industrial integration has an inverted U-shaped nonlinear effect on agricultural non-point source pollution, and second, urbanization plays a moderating effect on the relationship between the two and smoothes the inverted U-shaped curve.

In China, the process of rural industrial integration and urbanization will continue for a long time in the future, and the ecological environment in some regions does not improve as a result of the nonlinear impact that rural industrial integration can have on agricultural non-point source pollution. This implies that the contradictions between rural industrial integration development and agricultural production are not always well coordinated. Our findings have implications for the improvement of agricultural policies in China. First, the government can consider further improving the environment for the development of rural industrial integration and provide the corresponding material basis and sustainable development conditions to promote the development of rural industrial integration. For example, it can strengthen infrastructure construction, create industrial commons, rooted in knowledge and skills, participate in R&D and creation among various social organizations, create fertile soil for industrial integration with sufficient human capital, perfect science and technology, complete infrastructure, strengthen the empowerment of modern technology for agriculture, and realize the low-carbon development of agricultural production, so as to promote the integration of rural industries to exert a green effect. In addition, it can rationally plan the mode and structure of industrial integration to reduce the ecological damage caused by the initial stage of industrial integration development. Second, in light of the level of integrated development of rural industries in various regions, it can rationally promote urbanization, adjust the speed of urbanization according to local conditions, and promote the realization of the positive effects of urbanization. For areas that exceed the critical level of industrial integration, it is necessary to pay attention to the quality of urbanization, establish corresponding preferential policies, guide high-quality labor to return to their hometowns and help realize rural revitalization. Third, it can increase the government's financial support for agriculture, optimize and improve the relevant social security system, and at the same time encourage social funds to actively pour into the "three rural" construction, guide social funds to tilt towards agricultural and rural construction, and provide support for the development of rural industrial integration.

This paper explores the impact of rural industrial integration on agricultural non-point source pollution in China at the provincial level. However, there are still limitations in this paper, and there are still some aspects that can be improved and explored. First, in terms of sample selection, this paper uses province-level data in China, and the research period is only 9 years, so the sample size is relatively small and the empirical test results may have some bias. If city-level data were considered and the sample period was expanded, the study would have been richer. Second, the development of rural industrial integration has an impact on agricultural non-point source pollution. However, due to limited agricultural data, this paper only examines the impacts of rural industrial integration on pesticides, fertilizers and agricultural plastic films. Future studies should further explore this impact from other aspects such as livestock and poultry breeding type, pollution, rural living pollution, and farmland waste pollution. Third, so far, we have only considered the effect of urbanization on the relationship between rural industrial integration and agricultural non-point source pollution. There are many interesting elements and characteristics in this relationship that we have not explored. Finally, this paper is developed using China as a research sample. In some developed countries or regions where advanced agricultural technologies are already available, there may be only a linear relationship between rural industrial integration and agricultural non-point source pollution, and their nonlinear

relationship may not exist. In conclusion, future studies with better data conditions and theoretical foundations could consider improving these shortcomings.

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