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Part-Time Farming, Diseases and Pest Control Delay and Its External Influence on Pesticide Use in China's Rice Production

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The highly intensive use of pesticide is a big threat to environmental sustainability in China. This study explains the increase of rice pesticide use in China's rapid urbanization process from the perspective of changes in the delay of pest control. Based on multi-stage random sampling, 20 villages of five counties in central Jiangsu were selected, and the production data of 430 paddy fields were surveyed. Logit model results show that living outside village of agricultural labors will increase the probability of delay in control of diseases and pest, while the increase of farm size and the development of outsourcing services and public monitoring and forecasting services will help reduce the probability of delay. The OLS model results show that the delay in rice diseases and pest control has negative externalities. The delays of other farmers in the village will significantly increase the frequency of pesticide use. These results highlight important policy implications for the development of large-scale farming to substitute part-time farming and the development of diseases and pest control services.

Keywords: pesticide use, delay in agricultural production, labor migration, part-time farming, large-scale farms, outsourcing services

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INTRODUCTION

The intensity of China's pesticide use is among the highest in the world. The high-intensity use of pesticides has played an indelible role in controlling diseases, pests and weeds and maintaining the supply of agricultural products, but at the same time, it has brought about problems such as increased production costs, unsafety of food with excessive residues, crop phytotoxicity, and environmental pollution. As people value food safety, environmental protection and sustainability more highly, the high-intensity use of pesticides has become a hot issue. To control pesticide use, the Ministry of Agriculture in 2015 formulated the policy of "Zero Growth in Pesticide Use by 2020". Although the policy goal was achieved as soon as it was put forward, the intensity of pesticide use is still at high level and the reduction of pesticide use are still of importance.

Wheat, rice and corn are the three largest grain crops in China. In terms of pesticide use, the most noteworthy crop is rice. On one hand the rice is staple food, on the other hand its pesticide expenses per mu is three times that of wheat and corn (as shown in **Figure 1**). The reason why rice use so much more pesticide is mainly related to the severe migratory pests, such as rice planthoppers. In addition to the greater intensity, the trend of pesticide use of rice is also different from that of wheat and corn. Compared

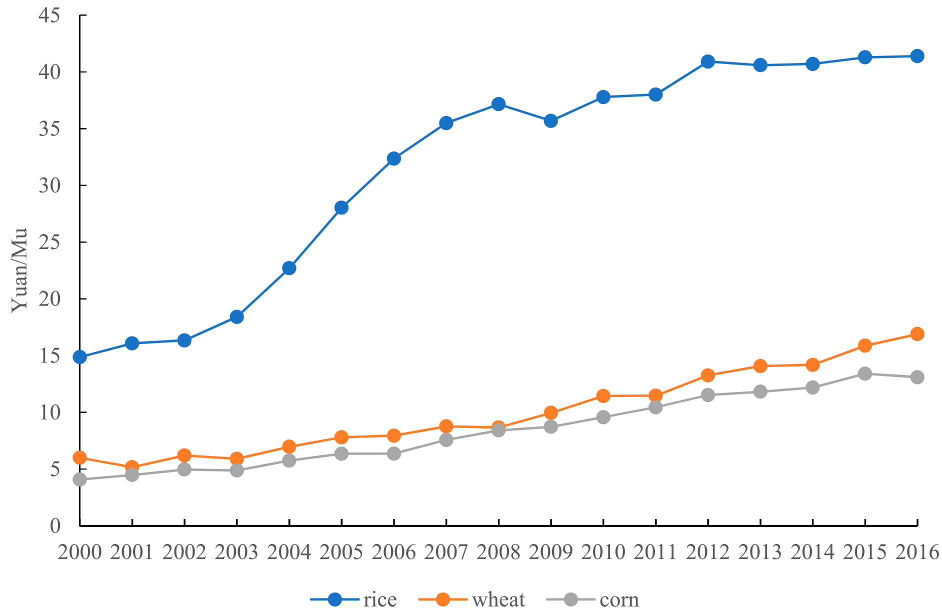

FIGURE 1 | Input of pesticide cost per mu for three main grain crops in China (2000–2016). Note: The original pesticide cost per mu data come from the yearbook of agricultural cost survey. The data reported in the figure has been deflated according to the price indices to the price in 2000. The price indices are the "price indices of pesticide and related equipment" from the China Statistical Yearbook.

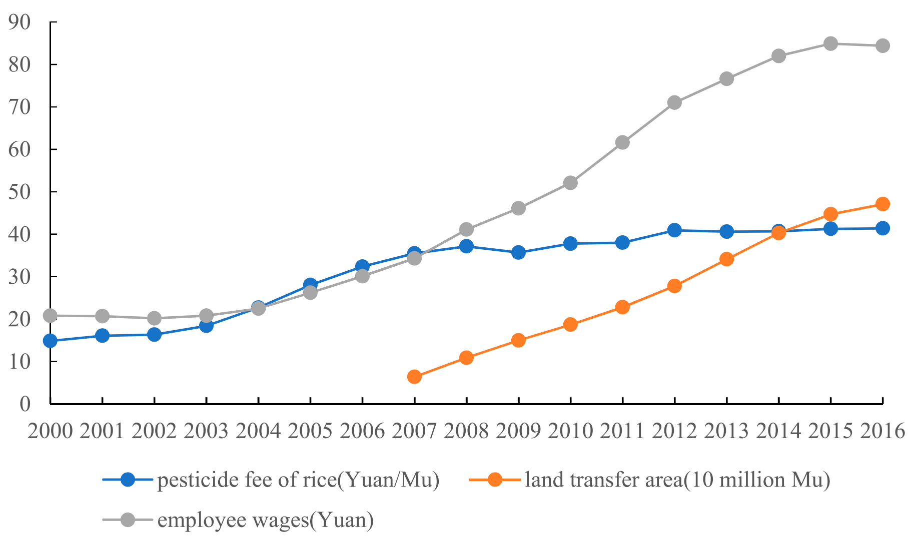

FIGURE 2 | Changes in land transfer, labor price and application intensity of rice in China (2000–2016). Note: The data of pesticide fee and wages are from the yearbook of agricultural cost survey. The data reported in the figure has been deflated. The deflation method of pesticide is the same as that in **Figure 1**. The wages of employees are deflated by the consumer price index of rural residents in the China Statistical Yearbook. The land transfer area data are from the statistical annual report of China's rural business and management.

with wheat and corn, which have been steadily increasing in pesticide expenses, the pesticide expenses per mu of rice increased rapidly from 2002 to 2008 and increased oscillatorily from 2008 to 2012 but did not increase significantly after 2012. Then, how to explain the different trends of pesticide use for rice? And what does it mean for the reduction of pesticide use?

The long-term increasing trend of pesticide use intensity in agricultural production is mainly explained by the existing literature from the aspects of environmental changes that are conducive to the outbreak of pests and weeds (such as climate warming), increased resistance to pests and weeds, and the decline of pesticide toxicity based on food safety

TABLE 1 | variable definition.

Variable Name	Variable Definition
Application times	Total frequency of pesticide use by farmers during rice planting in one season (Times)
Is pest control delayed	1 = yes; 0 = no
Proportion of delay in control of other households in the village	Proportion of other interviewed households in the village with “agricultural time” delay
Proportion of households that should be visited but not visited in the village	Proportion of rice growers who were included in the visit list but were failed to visit the village in the end
Residence of farmers and agricultural labor	0 = all agricultural labor living in the village; 1 = some live outside the village; 2 = all live outside the village
Is there an outsourcing service provider	Can the village hire a new outsourcing service provider? (1 = yes; 0 = no)
Public monitoring and forecasting services	Does the village committee convey the control information of the Agricultural Technology Department? (1 = yes; 0 = no)
Operating paddy field area	Total rice planting area (Mu)
Is there any spraying machinery	1 = have spraying machinery (excluding manual instruments); 0 = no
Number of agricultural labors	Number of people over the age of 16 who do not attend school and participate in agricultural labor
Agricultural training	Number of agricultural labors who have participated in agricultural training
Feminization	1 = the agricultural laborers are all women; 0 = other
Aging	1 = all agricultural laborers are older than 60 years old; 0 = other
Number of full-time nonagricultural employment labor	Number of people over 16 years old who do not go to school, and only participate in nonagricultural labor

considerations (Zhang, 2010; Hu et al., 2013). There is no research that reveals the different trends for rice in **Figure 1**. The main difference between rice and wheat or corn is that it faces more serious infectious pests. The unique trend may also be rooted in transmissible pests and their control.

Similar to the COVID-19 that humans are facing, expense on pesticides for pest control are related to the severity of pests and diseases, and the severity is related to the control behavior. Ji et al. (2015) and Chen et al. (2017) explained the increase of pesticide use from the perspective of farmers' part-time employment. They suggested that the agricultural labor engaged in off-farm activities could not flexibly arrange time for pest control, and the pattern of “simultaneous control” through “following the others” and accepting the guidance of the agricultural estension department has been broken, resulting in the cross-repetition of plant diseases and insect pests and the increase in the use of pesticides. The same trend in the increase of pesticide use and agricultural wages from 2002 to 2007 (as shown in **Figure 2**) seem to support the hypothesis of Ji et al. (2015) and Chen et al. (2017). Before 2002, there was still a large amount of surplus labor in rural China. So, the rapid increase of off-farm employment did not threaten the control of diseases and pests in that time. When it comes to 2003, the “shortage of migrant workers” in the southeast coastal areas shows that the surplus rural labor has been run out. And the wage of hired labors in the agricultural sector has also begun to rise rapidly. Due to labor shortages and delayed control, some farms turn out to be a natural shelter for migratory pests, which eventually leads to cross-repetition and frequent outbreak of pests, resulting in a rapid increase in pesticide per mu. However, after 2007, the pesticide use no longer increased with wages (as shown in **Figure 2**). This may be due to the rapid development of land transfer and the increase of large-scale farms. In other links in production chains, such as sowing and harvesting, large-scale farms are often faced with the risk of delays due to the bottleneck constraints of the family labor supply or regional labor supply. However, the amount of labor required for pest control is very limited. For large-scale farms, by using appropriate machinery or supplemented by readily available employed workers they are likely to be able to control pests on time. The delay in pest control may mainly occur in part-time farming smallholders who leave village during the pest control season. The substitution of large-scale farming to part-time farming or the emergence of outsourcing services of pest control may alleviate the threaten of labor migration on the delay of pest control.

Based the above discussion, the specific question to answer in this study is as follows: for the rice production which face serious migratory pests, will the control delay have a negative external impact on the surrounding farmers and make them use pesticide more times? What are the causes of farmers' delays in control? In particular, how did the part-time farming large-scale farming and the development of control services affect the occurrence of delays in control?

The existing economic research on pest control mainly focuses on the amount of pesticide use decision, which is considered to face the trade-offs between economy, health, environment and market risk (Galt, 2007). The factors affecting pesticide input include the personal characteristics of decision-makers (Doss and Morris, 2000; Isin and Yildrim, 2007; Ngowi et al., 2007; Wang et al., 2017), historical habits (Wilson and Tisdell, 2001), risk attitude and insurance (Paudel et al., 2000; Zhong et al., 2007; Huang et al., 2008; Bakker et al., 2021), farm size (Luo, 2020; Zhang, 2020; Zhu and Wang, 2021; Gao et al., 2021), information (Babu et al., 2012; Shahini et al., 2017), government policies and intensive land use (Templeton and Jamora, 2010; Riwthong et al., 2015; Femenia and Letort, 2016; Lamichhane and Ram, 2017; Migheli, 2017; Sun et al., 2021), technological progress (Lescourret, 2016), Household income and organization (Dasgupta et al., 2007; De Brauw and Rozelle, 2008; Kirezieva et al., 2016), natural conditions (Saphores, 2000; Dasgupta et al., 2007; Andert et al., 2015), participation in contract agriculture, cooperatives and public control service (Rahman, 2003; Hamilton and Sidebottom, 2011; Ying and Xu, 2014; Zhao et al., 2018; Lu, 2021). There are few studies on the delay of pesticide application in pest control, especially its negative externalities. Chen et al. (2017) discussed the relationship between service outsourcing and delays in crop pest control. Ji et al. (2015) found that the employment time of their own household labor will reduce the pesticide input, while the employment time of other households in the region will increase the pesticide input, and speculated that the former represents delay and the latter represents the negative externality of delay. Similarly, Shi et al. (2011) and Chen et al. (2017) found that nonagricultural and part-time employment will increase the asynchrony of pesticide application in villages and the intensity of pesticide use in rice production. Although the above studies had useful discussions and empirical analysis, there is still a lack of direct testing on the negative externality of pest control delay. The discussion on the causes of pest control delay mainly focuses on nonagricultural and outsourcing services, while discussions on scale farms are still relatively few.

In summary, the delay of rice pest control deserves special attention for the following reasons: First, for other links of production chains the delay only affects the farmers' own costs and benefits, but the delay in the control of infectious diseases and pests may also increase the costs of surrounding farmers. Public governance is needed to correct this negative externality. Second, rice is more threatened by infectious diseases and transmissible pests, and the intensity of pesticide use is higher. Reducing pesticide use is more important for protecting the ecological environment and improving the quality of rice. Third, although the existing research has had useful discussions on the causes of delays in the control of rice diseases, insect pests and their external influences, there is still room for improvement in theoretical discussions and empirical design.

This study intends to analyze the occurrence of delay in rice pest control and examine the impact of control delay of surrounding farmers on the frequency of pesticide use. To realize health-oriented agricultural production, the pollution-related agricultural inputs should be strictly restricted. The value of this study is investigating the pest control behavior of farmers from the new perspective of "time" and explaining the unique trend of pesticide use in China's rice production to providing new insights for policy making. The rest of this paper is arranged as follows: the second part is the theoretical analysis and model setting, the third part is the data source and descriptive statistics, the fourth part is the empirical results and discussion, and the last part is the conclusion and policy recommendations.

THEORETICAL FRAMEWORK AND EMPIRICAL MODELS

Theoretical Framework

(1) Farm size, labor transfer and the delay of farm production

Although the farm size in China is very small, seasonal labor shortages and farming time delays have also widely existed in the farming, planting and harvesting chains of agricultural production in the multi crop planting mode. Examples of this occur during the busy summer season in the rice–wheat cropping areas, the "three-grabbing" phenomenon of rushing to harvest wheat, rushing for planting and rushing to manage rice planting; and the phenomenon of having to harvest wheat in advance or delay rice planting and adjust planting structure due to "overwhelming busyness". The transfer of rural labor will obviously aggravate the seasonal labor shortage and bring about delays in farming time. However, in general, the progress of mechanical technology and the development of the outsourcing market in the past three or 4 decades have solved or alleviated the problem of farming time delays for small households under the existing varieties and planting systems in most areas. At present, delays in farming, planting, and harvesting stages mainly occur in the production of large growers. To reduce production costs, these large growers tend to strategically choose to stagger the planting time with small households to obtain low-cost hired labor or choose to use self-purchased large machinery for a longer time instead of employing multiple machines.

Planting and harvesting chains with intensive labor demand, large quantity and fixed season, with outbreak time of diseases and pests, especially disseminated pests, is random and different from farming. Accordingly, it is necessary to carry out daily investigation and rapid control when a disaster or omen is found. The amount of labor required to perform a single survey or spraying of pesticides is relatively small. For ordinary pure farmers, farming time delays rarely occur in the chain of pest control. Part of the family's labor is engaged in nonagricultural employment, which often does not hinder ordinary small households' pest control, as long as full-time labor engaged in agricultural farms is sufficient for pest control. Even some households in which all laborers are engaged in busy nonagricultural work locally, they can still carry out pest control in time with the help of neighbors or agricultural technology departments. Control delays may mainly occur in households in which all agricultural laborers live outside. With the development of labor transfer and urbanization, there are some agricultural operators who have lived in towns for a long time (for reasons such as work or taking care of their families). They mainly return home in fixed busy farming seasons, and they mainly live in towns in idle farming seasons. The separation of living places and agricultural production sites reduces the quality of operation and management. Farmers are unable to carry out high-frequency daily monitoring of the occurrence and development of diseases and pests, or they are unable to carry out control work in time when receiving a control notice due to insufficient flexibility of time arrangement. The development of labor transfer and living outside village highlights the importance of outsourcing services. The public monitoring and forecasting services can replace the daily survey work of farmers, and the market-oriented outsourcing service can further replace the pesticide spraying work of farmers, all of which help reduce the occurrence of delays in control.

The expansion of farm size can increase the total income of farmers from timely control of diseases and pests, but the total

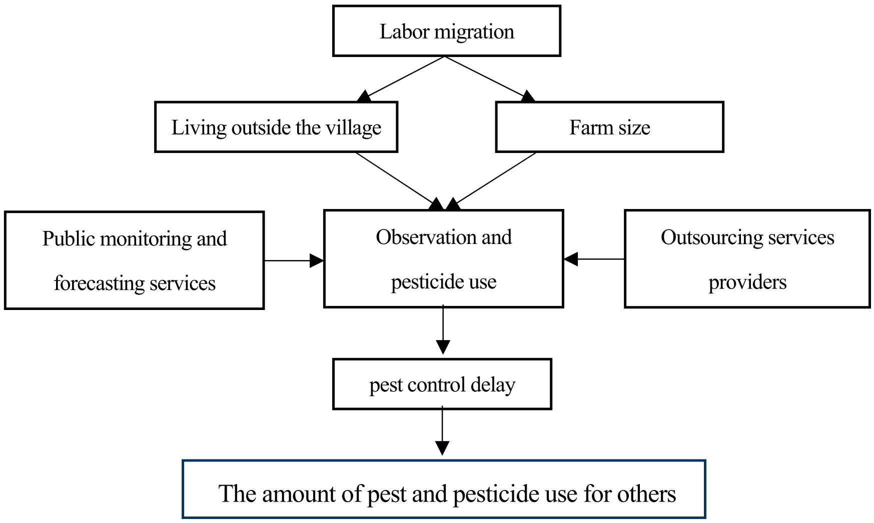

FIGURE 3 | Analysis framework of pest control delay under the background of labor migration.

cost of daily survey will not increase linearly with the farm size (the labor input for a survey of 100 mu land will not be several times more than that of 10 mu land). Therefore, large-scale households may pay attention more frequently to the occurrence and development of pests and diseases and actively search for early warning information issued by the agricultural technology department on pests and diseases to start control work in a more timely manner. When using the same tools and equipment, the working time of spraying pesticides is related to the farm size. During the intensive outbreak of diseases and insect pests, large-scale farmers may also face seasonal shortages of family labor and delays in farming time due to "overwhelming busyness". However, compared with other chains, the amount of labor required to spray pesticides is very small, and there are many tools and equipment with different operating capabilities to choose from (such as traditional backhand pressure sprayers, motorized sprayers, self-propelled boom sprayers and plant protection aircraft). On the other hand, large-scale households can use the surplus labor of other small households or use the machinery services provided by professional plant protection organizations, to also complete the control work in time or even in more timely manner than small households.

Based on the above analysis of the characteristics of pest control investigation and pesticide application, this paper puts forward the following hypothesis about the delay of pest control: 1. Living outside village of labors will increase the delay, and the development of large-scale farms and pest control services will reduce the delay.

The theoretical analysis is shown in **Figure 3**:

(2) Analysis of the delay of pest control and its effect on pesticide use

The total amount of pesticides applied by farmers per mu of land closely related to the frequency of pesticide application, and the frequency of pesticide application is closely related to the occurrence and development of diseases, insects and weeds. As the two major chemical inputs in agricultural production, pesticides and fertilizers are often analyzed by researchers under the same conceptual framework. However, there are great differences in investment decisions between pesticides and fertilizers. Farmers' fertilizer input decision-making has stronger initiative, and they can even "apply fertilizer in advance" and use "less times but more quantity"; that is, to ensure that crops have sufficient fertilizer supply at all stages, farmers must double the amount of fertilizer each time and increase the total amount of fertilizer when reducing the times of fertilization (Ji et al., 2016). In contrast, farmers' pesticide input belongs to passive decision-making, and the total pesticide demand of crops and the timing of pesticides application are uncertain, so it is technically difficult to use them "in advance": on the one hand, the efficacy of pesticides, especially the highly respected low toxicity and high degradation pesticides, generally lasts for a short time; on the other hand, the newly grown young stems and leaves need to be protected, and pests will seriously affect the growth and yield of crops. Therefore, the total pesticide demand of crops mainly depends on the occurrence and development of diseases, pests and weeds. The more plant diseases, pests and weeds occur, the more times that they need to be prevented and controlled, and the greater the amount of pesticides used. Based on this, the following theoretical discussion and empirical analysis will focus on the frequency of application rather than the amount of pesticide use that is difficult to measure. The relationship between pesticide application delay and the frequency of pesticide application by farmers is mainly described by the following three aspects.

First, the delay in the control of disseminated pests has a negative external impact, which will increase the occurrence times of pests and the pesticide application frequency of other farmers in adjacent plots. This is because the delayed application of the rice field is a refuge for the transmission of pests, and the second migration will occur when the efficacy of the applied rice field disappears. Therefore, when the pest control of other farmers in adjacent plots is delayed, the application frequency of farmers will be increased.

Second, when the number of occurrences of diseases and insect pests is the same, the factors that increase the delay in control often have the effect of reducing the number of pesticides' applications. For example, when agricultural operators cannot detect and control diseases and pests in time due to living outside, farmers also reduce the frequency of pesticide application accordingly. The development of large-scale farms and social services enable farmers to obtain the information about diseases and pests in time and control them in time, which will increase pesticide application accordingly.

Finally, other related factors may also affect the frequency of application by affecting the control effect. The frequency of application is related not only to the occurrence of diseases and pests but also to the control effect. A poor control effect will increase the follow-up control frequency. The control effect mainly depends on three factors: 1) Control timing. The factors that increase control delay may also increase the frequency of application by reducing the control effect. 2) Pesticide selection. The development of resistance to plant diseases, insects and weeds means that the types of pesticides used need to be updated constantly. Farmers with relatively small scale spend a high price gaining new pesticide selection knowledge and often face uneconomical problems. Large-scale farms and the notification of pesticide types by agricultural technology departments can improve the control effect and reduce the frequency of application. 3) Operation quality. Operation quality is related not only to the tools and equipment used but also to the personnel performing the operations. In case of the former, large-scale farms and the development of outsourcing services will promote the substitution of large-sized plant protection machinery for hand tools; in case of the latter, it is generally believed that compared with domestic labor, employment has a tendency to reduce the quality of work (Sun et al., 2019).

The direct effect of living outside makes farmers miss control and reduce the frequency of pesticide application, but it may also increase the difficulty and frequency of follow-up control due to missing the best time of control. As an alternative to self-treatment, outsourcing services is expected to play the opposite role of living outside. The development of public monitoring and forecasting services can prevent farmers from missing control due to failure to detect the disaster and increase the number of control, but it is more likely to improve the control effect to reduce the frequency of application.

Based on the above analysis of delay and pesticide application frequency of farmers, this paper puts forward Hypothesis 2 (2a) the delay of other households in the village has a negative externality of increasing pesticide application frequency of farmers (2b) living outside village of labors and outsourcing services have the opposite impact on the frequency of pesticide application; and (2c) public monitoring and forecasting services can improve the control effect and reduce the frequency of control.

Empirical Models

(1) Delay in pest control model

Based on the analysis of labor characteristics in disease and pest control, this paper constructs a logit model to test the influencing factors of rice disease and pest control delay. The model is set as follows:

$$Y = \alpha_1 + \beta_1 Al + \beta_2 Ser + \beta_3 Inf + \beta_4 Area + \lambda_k D_k + \mu \quad (1)$$

The selection of model variables and the construction of indicators are described below.

The explanatory variable Y represents whether there is a "farming time" delay in rice pest control, which is based on the self-evaluation of farmers. This is the overall evaluation of the timeliness of rice pest control in the current season after rice harvest.

The key explanatory variable Al is the main agricultural labor residence of the household. Considering that many rice pests (such as brown planthoppers and rice leaf rollers) are migratory, it is difficult to accurately predict their migration path and population growth (China Society of Plant Protection, 2015). Even if there is pest prediction information and pesticide application time reminders from the Agricultural Plant Protection Department, it is still necessary for farmers to observe the changes in the number of pests in the field and apply pesticides in time. Since the amount of labor required for a single survey or pesticide spraying task is relatively small, local nonagricultural employment may have little impact on control, so the main analysis is the impact of living outside. The residential areas of farmer households are divided into three types: all living in the village, some living outside the village and all living outside the village. The key explanatory variable Ser is the availability of outsourcing services in the village, which is measured by whether there is an outsourcing service provider in the village, and Inf is the availability of public monitoring and forecasting services, which is measured by whether the pest control information is given by the Agricultural Technology Department through door-to-door leaflets or village broadcast. In addition, the key explanatory variable $Area$ is the paddy field area of the household, which is used to analyze the impact of large-scale farms on pest control.

The control variables D_k are mainly labor characteristics and the holding of control machinery. The labor characteristics include the number of agricultural laborers, the number of agricultural laborers who have participated in training, whether all agricultural workers are women (feminization), whether they are all elderly people over 60 (aging), and the number of laborers who participate in nonagricultural employment full-time.

(2) Pesticide use model

Based on the above analysis of the externality of delay in the control of spreading diseases and insect pests and the number of pesticides' applications by farmers, this paper constructs an OLS model to test the influencing factors of the number of farmers' pesticide applications. The model is set as follows:

$$Y = \alpha_1 + \beta_1 Del + \beta_2 Al + \beta_3 Ser + \beta_4 Inf + \lambda_k D_k + \mu \tag{2}$$

The selection of model variables and the construction of indicators are described below.

The explained variable Y is the total number of pesticides' applications in rice production. Accurate pesticide application frequency in the sample rice field were obtained through multiple surveys. The key explanatory variable Del is the proportion of disease and pest control delay in other interviewed households in the village, which is used to analyze the negative external impact caused by control delay in other households. In addition, during the investigation, a small number of rice growers included in the interview list were unable to obtain their control delay information, but they also had the possibility of control delay. Therefore, the proportion of rice growers who were interviewed but had not been visited was also put into the model for analysis. The selection of other variables in the model is the same as the control delay model.

According to the setting and analysis of the above two models, the selection and definition of variables in the empirical model are shown in the **Table 1**.

DATA AND DESCRIPTIVE STATISTICS

Data Source

The data used in this paper are based on a 2016 survey in the central Jiangsu of China. Jiangsu is one of the major rice producers, accounting for 9.38% of China's total rice output in 2015, ranking fourth in all provinces. The data cover the population and employment, the use of land, detailed production information of sample paddy fields, etc. A total of 447 questionnaires were collected, and 430 valid samples were obtained by excluding the missing samples of the explained variables of the application frequency and the delay of pest control.

Five adjacent counties located in the central Jiangsu with similar temperatures, precipitation and altitudes are selected, namely Dafeng, Dongtai, Xinghua, Gaoyou and Baoying. Four villages were randomly selected from each county, and then a paddy field was randomly selected from each village. Pest control behaviors of all farmers in that paddy field were investigated. To accurately record the time information of each pest control in the sample paddy field, five visits were conducted from sowing to harvest, with an interval of approximately 1 month. The variable of the number of applications is the sum of the number of applications in each survey. The variable representing delay in pest control is based on the subjective evaluation of farmers in the last survey in 2016.

Data Description Statistics

Table 2 reports the descriptive statistical results of the overall survey data. It can be seen from the table that the average number of applications is 5.99, the minimum value is 1 and the maximum value is 12. On the one hand, there are great differences in application behavior among farmers with different characteristics. On the other hand, because this survey is a follow-up survey for five consecutive months, the maximum value may be caused by survey errors. The average proportion of delays of other households in the village is 0.15, and the average value of the "farming time" delay variable of pest control is 0.2, indicating that 20% of farmers had experience of delay in pest control, and the delay of pest control cannot be ignored.

There were as many as 18 villages with public monitoring and forecasting services in 20 villages in the central Jiangsu of China during the data survey period, which basically achieved coverage from the perspective of the availability of services. However, there are still major deficiencies in the development of outsourcing services. Only 31% of the respondents answered that the village can hire corresponding services.

Among the 430 households, there were 50 households in which all agricultural laborers lived outside the village, accounting for 11.63%, and 48 households in which some laborers lived outside the village, accounting for 11.16%, which covers the perspective of the type of farmer. Although the agricultural laborers of the surveyed farmers are still mainly living in villages, the separation of residences and agricultural production places cannot be ignored. The proportion of female households is 14% and that of elderly households is 59%, indicating that the aging trend of agricultural labor is more obvious at the current stage. The average number of agricultural laborers participating in agricultural training is 0.18, indicating that the current development of agricultural training is still not very satisfactory.

MODEL RESULTS AND DISCUSSION

Basic Regression

Table 3 shows the basic regression results of the analysis model of influencing factors of farmers' delay in pest control and the analysis model of influencing factors of farmers' application frequency. The specific analysis is as follows.

(1) Empirical results of pest control delay

The key explanatory variable of all the agricultural labor of the household living outside the village has a significant positive impact on the delay of rice pest control, which indicates that living outside the village will increase the delay of rice pest control, but it will have a significant impact only when all the agricultural labor live outside the village. There are two reasons for this: first, the households with all laborers living outside the village are unable to observe the occurrence and development of rice diseases and pests in time, or even if they know the diseases and pests, they cannot go home in time for treatment; second, the amount of labor required for a single survey or pesticide spraying task is relatively small. As long as full-time labors engaged in agricultural production are retained, it is sufficient to be competent for pest control.

The key explanatory variables of the village having outsourcing service providers, and public monitoring and forecasting services have a significantly negative impact at the level of 1% on the delay of rice pest control, which indicates that the development of services (private service and public management service) helps to reduce the

TABLE 2 | variable description statistics.

Variable Name	Observed Value	Average Value	Standard Error	Minimum Value	Maximum
Application frequency	430	5.99	2.31	1	12
Is pest control delayed	430	0.20	0.40	0	1
Proportion of delay in control of other households in the village	430	0.15	0.09	0	0.35
Proportion of households that should be visited but not visited in the village	430	0.19	0.14	0	0.50
Residence of farmers and agricultural labor	430	0.34	0.68	0	2
Is there an outsourcing service provider	430	0.31	0.46	0	1
Public monitoring and forecasting services	430	0.84	0.37	0	1
Operating paddy field area	430	13.52	67.98	0	1,170
Is there any pesticide spraying machinery	430	0.81	0.39	0	1
Number of agricultural labors	430	1.75	0.83	0	5
Agricultural training	430	0.18	0.51	0	3
Feminization	430	0.14	0.35	0	1
Aging	430	0.59	0.49	0	1
Number of full-time nonagricultural employment labor	430	0.08	0.45	0	4

TABLE 3 | benchmark model regression results.

Variable Name	Pest Control Delay (logit Model)	Times of Pesticide Use (OLS Model)
Proportion of delay in control of other households in the village		4.678*** (1.232)
Proportion of households that should be visited but not visited in the village		1.179 (0.830)
Residence of agricultural labor of the household (refer to all living in the village)		
Some live outside the village	0.105 (0.437)	−0.942** (0.369)
All live outside the village	0.665* (0.392)	−0.516 (0.355)
Is there an outsourcing service provider	−1.142*** (0.335)	0.930*** (0.236)
Public monitoring and forecasting services	−1.184*** (0.336)	−0.502* (0.303)
Paddy field area of the household	−0.0789** (0.0317)	−0.0008 (0.0016)
Is there any spraying machinery	−0.333 (0.324)	0.539* (0.283)
Number of agricultural labors in the household	0.0442 (0.208)	0.289* (0.167)
Agricultural training	0.0281 (0.297)	0.289 (0.223)
Feminization	0.0508 (0.436)	0.856** (0.360)
Aging	0.521* (0.280)	0.0555 (0.227)
Number of full-time nonagricultural employment labor in this household	−0.0261 (0.289)	0.176 (0.261)
Constant term	0.0853 (0.578)	4.204*** (0.564)
Observed value	430	430
R-squared		0.105

*Note: (1) ***, **, * indicate significance at the significance levels of 1, 5 and 10%, respectively. (2) The numbers in brackets are the standard error of variables.*

adverse impact of labor migration on rice pest control. The quantitative constraint of labor on the timeliness of rice pest control is alleviated by developing outsourcing services, and the information constraint of field observation on the timeliness of rice pest control is solved by providing public monitoring and forecasting services.

The key explanatory variable of paddy field area has a significantly negative impact at the level of 1% on the delay of rice pest control, which indicates that for large-scale farmers, the benefit of timely pest control is higher than the cost, and the farmers are more motivated to timely control pests. Therefore, the expansion of the farm size helps to reduce the delay of pests control, which is consistent with the results of theoretical analysis.

In summary, living outside village of labors will increase delays, and the development of large-scale farms and services is conducive to reducing delays; that is, Hypothesis 1 is established. In addition, in terms of control variables, aging significantly increases the possibility of delay in rice pest control at the statistical level of 10%.

(2) Empirical results of farmers' pesticide application use

The key explanatory variable of the proportion of delay in pest control of other households in the village has a significant positive impact at the level of 1% on the number of farmers' pesticide application, which indicates that the control of rice diseases and insect pests is not a matter for individual farmers,

TABLE 4 | regression results of model robustness test.

Variable Name	Pest Control Delay (ologit Model)	Times of Pesticide Use (excluding Samples less than 3 times)
Proportion of delay in control of other households in the village		3.981*** (1.108)
Proportion of households that should be visited but not visited in the village		1.933** (0.756)
Residence of agricultural labor of the household (refer to all living in the village)		
Some live outside the village	0.301 (0.434)	−0.957*** (0.339)
All live outside the village	0.713* (0.389)	−0.339 (0.331)
Is there an outsourcing service provider	−1.189*** (0.334)	0.750*** (0.215)
Public monitoring and forecasting services	−1.083*** (0.325)	−0.590** (0.278)
Paddy field area of the household	−0.0811** (0.0320)	-0.0013 (0.0014)
Is there any spraying machinery	−0.514 (0.323)	0.608** (0.259)
Number of agricultural labors in the household	0.0719 (0.203)	0.280* (0.152)
Agricultural training	0.0206 (0.294)	0.222 (0.201)
Feminization	−0.0115 (0.424)	0.895*** (0.328)
Aging	0.538* (0.275)	0.158 (0.209)
Number of full-time nonagricultural employment labor in this household	−0.0599 (0.268)	0.00492 (0.234)
Constant term		4.482*** (0.515)
Observed value	430	405
R-squared		0.117

*Note: (1) ***, **, * indicate significance at the significance levels of 1, 5 and 10%, respectively. (2) The numbers in brackets are the standard error of variables.*

and the delay of pest control has significant negative externalities. When the control of diseases and insect pests in a paddy field is insufficient, it will become a shelter for infectious diseases and insect pests. When the efficacy of pesticides disappear, diseases and pests will secondarily infect or migrate to the paddy fields, which will increase the frequency of pests and diseases and the frequency of pesticide application of other farmers in adjacent plots.

The variable of part of the agricultural labor living outside the village has a significantly positive impact at the level of 5% on the pesticide application frequency, but the impact of all the agricultural labor living outside the village on the pesticide application frequency of farmers is not significant. The reason is that compared with the farmers whose main agricultural labor all live in the village, the farmers whose main labor all live outside the village may reduce the application frequency due to missing control, while they may also increase frequency of follow-up control due to missing the best control time. The key explanatory variable of whether there are outsourcing service providers in the village has a significant positive impact on the number of pesticides' applications. As an alternative to self-control, the outsourcing services can alleviate the adverse impact of agricultural labor living outside on farmers' pest control.

The variable of paddy field area have a negative effect on the frequency of pesticide application, which was not statistically significant, but the negative coefficient indicates that the average frequency of pesticide application of large-scale farmers was less than that of small-scale farmers. Therefore, the increased scale of operations helps to reduce the number of applications and the use of pesticides.

The variable of public monitoring and forecasting services have a significant negative effect on the frequency of pesticide application, which shows that public monitoring and forecasting services have the effect of improving the effectiveness of control and reducing the frequency of control. In terms of control variables, the variables of the household with pesticide spraying machinery, the number of agricultural labor force and feminization have a significant positive effect on the frequency of pesticide application.

Robustness Test

To further verify the reliability of the regression results, this paper conducted a robustness test on the times of pesticide use and pest control delay.

Taking into account the actual investigation process, the application frequency may be missed due to multiple investigations. This paper eliminates farmers with application frequency less than 3 times and runs regression of Model 1) again. At the same time, the delay degree of rice pest control is used to replace whether rice pest control is delayed or not. The delay degree is divided into four grades: "1. No; 2. Slight; 3. General; 4 serious". The regression results are shown in **Table 4**. The regression results in **Table 4** and **Table 3** are basically consistent, which shows that the regression results in this paper are relatively robust. From **Table 4**, we can see that in the model of pesticide application frequency, the coefficient and significance of the key explanatory variables are basically consistent with the regression results in **Table 3**. Compared with the whole sample, after excluding the farmers whose application frequency is less than 3 times, the variable of the proportion of households that should be visited but not visited in the village has a significant positive impact on the farmers' application times. In the model of factors of delay in disease and pest control, the coefficients and significance of the key explanatory variables are also basically consistent with the regression results in **Table 3**.

CONCLUSION AND POLICY RECOMMENDATIONS

Based on the survey data of micro farmers in 20 villages of five counties in the central Jiangsu of China in 2016, this paper empirically discusses the causes and external impact of rice pest control delay. The empirical results show that 1) The separation of residences and production places caused by labor migration will increase the probability of control delays. 2) The expansion of farm size, the improvement of the availability of outsourcing services and the development of public monitoring and forecasting services will help reduce the probability of control delay. 3) The delay of rice pest control has a very obvious negative externality, and the delay of other households in the village has a negative externality of increasing the frequency of pesticide application. 4) Public monitoring and forecasting services can improve the control effect and reduce the number of control measures.

The micro empirical results of this paper are helpful to better understand the change in the intensity of pesticide use of rice in China. For rice, which is threatened by infectious diseases and insect pests, the frequency of pest outbreaks and the use of pesticides are affected by the residence of agricultural operators, farm size, and pest control services. The increase of agricultural labors living outside had led to the negative external impact of delayed control of transmissible diseases and pests, but the development of the land transfer market and outsourcing services for pest control alleviated the "farming time" delay. Therefore, the momentum of rapid growth of pesticide cost per mu of rice has been successfully curbed.

Based on the above conclusions and discussions, this paper puts forward the following three suggestions. First, to reduce the negative impact of the separation of agricultural labor residence and production location on agricultural pest control caused by labor migration, the government can take appropriate measures to promote the transfer and concentration of land to large professional households (such as subsidize continuous land transfer), and scale back the agricultural management model in which the main agricultural laborers live abroad. Second, in order to effectively replace farmers' self-control, we should focus on improving the quality of outsourcing services and reducing the price of services (such as subsidize outsourcing services), and in order to eliminate supervision difficulties, we should establish long-term cooperative relationships between farmers and outsourcing services. Finally, relevant government departments should further strengthen public monitoring and forecasting services of plant diseases and insect pests, improve the information dissemination channels of plant diseases and insect pest control, guide farmers to use pesticides to improve the control effect of plant diseases and insect pests and reduce the frequency of pesticide application. Where conditions permit, we can pilot and promote public control for highly contagious diseases and pests instead of self-control and autonomy of small farmers. China is implementing the green development of agriculture, the conclusion of sustainable agriculture in China can provide reference for other developing countries.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

CF Conceived and designed the analysis Collected the data Wrote the paper YX Collected the data Performed the analysis YJ Conceived and designed the analysis tools The survey design.

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