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Impacts of China's Minimum Grain Procurement Price Program on Agrochemical Use: A Household-Level Analysis

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Abstract: China's minimum grain procurement price program aims to boost grain production and ensure food self-sufficiency. It may also affect the already very high levels of chemical fertilizer and pesticides consumption, but little is known about these potential side-effects. In this paper, we apply panel data regression techniques to a large rural household-level data set for the period 1997–2010 to examine whether and how the minimum grain procurement price program affected households' agrochemical use. We find that the minimum grain procurement price program negatively affected both chemical fertilizer and pesticides use, with pesticides use being more responsive than the use of fertilizer. The higher wheat and rice prices that resulted from the program stimulated the use of agrochemicals, but they also stimulated area expansion which contributed to lower agrochemical use per unit of land. These counteracting indirect effects were overshadowed by the large negative direct effect of the minimum procurement price of rice on the use of fertilizer and pesticides.

Keywords: minimum grain procurement price; fertilizer; pesticides; sown area; households; China

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1. Introduction

Minimum support price policy has been widely used in developing countries, such as Bangladesh, Brazil, Chile, Ethiopia, India, Indonesia, Kenya, Malawi, Nigeria, Pakistan, Thailand, Turkey, and Zambia [1,2]. The common goals behind this policy are to increase food production and ensure food security [2]. China implemented a minimum procurement price program for rice in 2005 and for wheat in 2006, aiming to boost grain production and ensure food self-sufficiency [3,4]. As grain production fell to a historical low of 431 million tons in 2003 and the government grain stock decreased to its lowest level in 2004 [4], China replaced its centuries-old policy of taxing agriculture by subsidizing and providing price support to grain producers [4–6]. The minimum prices were relatively low in the first few years of implementation, rose rapidly after the world food crisis in 2008, and slightly declined recently [7,8].

Minimum support price may strongly affects the use of agricultural production inputs [9–11]. According to standard economic theory, minimum support price is expected to raise the grain price (see e.g., Li et al. [7], Kozicka et al. [9], Qian et al. [12], Kim and Chavas [13], Lyu and Li [14], Qian et al. [15], and Tripathi [16]), and thereby stimulate the use of agrochemicals and other variable inputs [5,17–19]. However, only a limited number of studies, such as Li et al. [7], Qian et al. [12], Ali et al. [20], Aditya et al. [21], Krishnaswamy [22], Chintapalli and Tang [23], and Ritu et al. [24], provided empirical evidence of this. Most of these studies focus on minimum support price influencing land area in India. They do not consider the influence on other inputs, particularly agrochemical use, which may pollute the environment [25,26]. Using a village computable general equilibrium model in which land is a non-tradable, Heerink et al. [5] estimated that the 36.6%

increase in the rice price in China during the period 2000–2004 caused 34% and 90% increases in fertilizer use in the two examined villages, respectively; estimated increases in pesticides use amounted to 28% and 80%. The estimated increases were partly caused by a shift in production from other crops towards rice, for given land-holding sizes.

The minimum grain procurement price may also affects agrochemical use in an indirect way. Higher procurement price may stimulates the expansion of land sown with grain, particularly when land is tradable as is the case in China in recent years with the rapid development of the rural land rental market. Given that farm size or sown area is generally found to have a negative effect on agrochemical use per unit of land (e.g., [25,27,28]), this implies that a negative indirect relationship may exist between higher grain (procurement) price and agrochemical use with land area sown with grain being the intermediate variable. The net effect on agrochemical use of these two counteracting mechanisms is unclear a priori.

Whether and how the minimum grain procurement price affects Chinese households' agrochemical use is an issue of great importance since China is the largest chemical fertilizer and pesticides consumer in the world [25]. After introducing the minimum grain procurement price program, China's grain output achieved a growth rate of 54% from 2003 to 2019. However, chemical fertilizer and pesticides consumption also rose by 22.5% and 4.5%, respectively, during the same period [29]. Since 2007, the amounts of chemical fertilizer and pesticides used in China are both higher than the amounts used by major crop exporters such as the USA, France, and Japan [25]. To reduce the use of chemical fertilizer and pesticides, China's Ministry of Agriculture has launched programs in recent years aimed at reducing the growth rate of agrochemical use [30], regulating high-toxic pesticides and stimulating low-toxic biological pesticides use and encouraging the use of organic fertilizer in fruit, vegetable, and tea production [31,32].

Despite its relevance for policy making, little is known about the impact of China's minimum grain procurement price program on the use of agrochemicals [4,6]. To address this knowledge gap, we use a large-scale household-level panel data set to examine whether and how the minimum grain procurement price program affected households' agrochemical use. The data set that we use for this purpose comprises Rural Fixed Observation Points survey data, a large-scale household-level panel data set collected since 1986 by the Research Center for Rural Economy (RCRE) of the Ministry of Agriculture. We have access to the survey data that were collected until the year 2010. Although we do not have access to more recent data, important insights about the impact of the minimum grain procurement price program on the use of fertilizer and pesticides can be obtained from such an analysis.

This study makes two contributions to the available literature. First, it expands the literature on the effects of minimum procurement price by focusing on agrochemical use at the rural household level. It thereby provides insights into potentially important environmental effects in China and other developing countries applying minimum support price, that may either conflict with or reinforce ongoing policies aimed at reducing agrochemical use. Second, our study takes into account the potential indirect effect of grain price on agrochemical use through changes in land areas sown with grain, which is not examined in the available literature on grain price and agrochemical use [5,19].

The rest of the paper is organized as follows. Section 2 briefly introduces the minimum grain procurement price policy in China. Section 3 describes the methodology and data set. Section 4 presents and discusses the estimation results. Section 5 provides conclusions and discusses potential policy implications.

2. China's Minimum Grain Procurement Price Policy

The minimum procurement price program for rice (*PMR*) and wheat (*PMW*) aims to ensure that grain prices are high enough to cover production costs and to help rural households earn a profit from growing grain crops. They are regarded as measures that stimulate grain production and protect farmers' interest [3,6]. The core of the minimum grain procurement price program is an assurance to farmers that authorities will not allow prices to fall, which sent a "strong signal" to help the rural households build expectations on ever-rising prices [6].

Following the *PMR* and *PMW* that started in 2005 and 2006, respectively, a temporary storage program was implemented for maize, soybean, and rapeseeds in 2008 with the aim to stimulate production of a wider range of major crops [4]. Given that the focus of our study is the minimum grain procurement price program, we confine the analysis to rice and wheat.

The minimum grain procurement price is set by China's National Development and Reform Commission (NDRC), Ministry of Agriculture (MOA, called Ministry of Agriculture and Rural Affairs since 2018) and other governmental institutions based on production costs and market conditions. It is announced before the crops are sown (September for wheat, January for rice) each year [6,33]. If the prevailing domestic market price falls below the minimum price, the state-owned China Grain Reserve Corporation (Sinograin) and its branches as well as qualified enterprises entrusted by Sinograin are authorized to directly purchase qualified grain from farmers at the applied minimum grain prices in designated major grain production areas [3,33].

Table 1 provides an overview of the officially applied minimum prices for wheat and rice in the designated major grain production areas. Some provinces joined the *PMR* in 2008 only. As can be seen from the table, the minimum grain procurement prices were raised considerably during the years 2008/2009–2014. In recent years, they remained constant and were even lowered in some years.

Table 1. Officially applied minimum grain prices (yuan/kg, current-year prices).

Crop & Type	White Wheat	Red/Mixed Wheat	Early Indica Rice	Mid/Late Indica Rice	Japonica Rice
Designated Provinces / Year	Henan, Hebei, Jiangsu, Anhui, Shandong, Hubei	See 'White Wheat'	Hunan, Hubei, Jiangxi, Anhui, Guangxi [a]	Jilin, Anhui, Jiangxi, Hubei, Hunan, Sichuan, Heilongjiang, Liaoning [a], Jiangsu [a], Guangxi [a], Henan [a]	See 'Mid/Late Indica Rice'
2005			1.40	1.44	1.50
2006	1.44	1.38	1.40	1.44	1.50
2007	1.44	1.38	1.40	1.44	1.50
2008	1.44	1.38	1.54	1.58	1.64
2009	1.74	1.66	1.80	1.84	1.90
2010	1.80	1.72	1.86	1.94	2.10
2011	1.90	1.86	2.04	2.14	2.56
2012	2.04	2.04	2.40	2.50	2.80
2013	2.24	2.24	2.64	2.70	3.00
2014	2.36	2.36	2.70	2.76	3.10
2015	2.36	2.36	2.70	2.76	3.10
2016	2.36	2.36	2.66	2.76	3.10
2017	2.36	2.36	2.60	2.72	3.00
2018	2.30	2.30	2.40	2.52	2.60
2019	2.24	2.24	2.40	2.52	2.60
2020	2.24	2.24	2.42	2.54	2.60
2021	2.26	2.26	2.44	2.56	2.60

Note: [a] Policy started in 2008. Sources: [3,4] for 2005–2011, [34] for 2012–2015, and various online policy documents after 2016 (details available upon request from first author).

3. Methods and Materials

To examine whether and how China's minimum grain procurement price affects households' agrochemical use, we carried out an empirical study taking the following steps. First, a theoretical framework was developed and used to derive testable hypotheses are given. Second, an empirical model that can be used for testing these hypotheses was developed based on available (agricultural) economic theory and taking into account the available information in the panel data set that we used for this study. Below we explain these two steps, followed by an introduction into the data set that was used and a discussion of the method used for estimating the empirical model.

3.1. Theoretical Framework

Using the standard approach in agricultural economics, e.g., Sadoulet and De Janvry [17], we consider a risk-neutral rural household using chemical fertilizer X_1, chemical pesticides X_2, land area A, and other regular productive inputs X_z to produce output Y that aims to maximize profit π, and with P, p_1, p_2, p_A, and p_z defined as the prices of Y, X_1, X_2, A, and X_z, respectively. Following Lichtenberg and Zilberman [35], we specify chemical pesticides use as a damage control agent $G(\cdot)$ that represents the effectiveness of pesticides in limiting yield losses, with $G(\cdot) \in [0,\ 1]$. The output generated by other inputs is assumed to satisfy a Cobb–Douglas production function $F(\cdot)$. This gives the damage-abatement production function $Y(\cdot)$, in which θ represents the probability of occurrence of pests, weeds, and diseases in crops, with $\theta \in [0,\ 1]$. Following Schreinemachers et al. [36], we use the exponential specification for the damage control agent $G(\cdot)$ in this study. Referring to Li et al. [7], Li and Chavas [8], and Qian et al. [12], the grain price P depends on the world market grain price WP and on domestic factors, i.e., the minimum grain procurement price PM and other factors Z affecting the supply of grain. This gives:

$$\text{Max } \pi = PY - p_1X_1 - p_2X_2 - p_AA - p_zX_z \tag{1}$$

subject to:

$$P = P(PM, WP, Z) \tag{2}$$

$$Y = (1-\theta)F(X_1, A, X_z) + \theta F(X_1, A, X_z)G(X_2) \tag{3}$$

$$F(X_1, A, X_z) = \alpha X_1^{\varphi_1} A^{\varphi_2} X_z^{\varphi_3} \tag{4}$$

$$G(X_2) = 1 - e^{-\lambda X_2} \tag{5}$$

Given that the minimum grain procurement price intends to raise the prices that farmers receive for the rice and wheat they produce, we assume that $\frac{\partial P}{\partial PM} > 0$. This gives the following hypothesis:

Hypothesis 1. *The minimum grain procurement price positively affects the grain price that rural households receive.*

Let $X_1^{*A} = X_1^*/A$ and $X_2^{*A} = X_2^*/A$ be the optimum quantities per unit land of fertilizer and pesticides, respectively. Applying first-order conditions gives:

$$A^* = P^{(1-\varphi_2)^{-1}} \left[p_A^{-1} \varphi_2 \alpha X_1^{\varphi_1} X_z^{\varphi_3} \left(1 - \theta e^{-\lambda X_2}\right) \right]^{(1-\varphi_2)^{-1}} \tag{6}$$

$$X_1^{*A} = P^{(1-\varphi_1)^{-1}} \left[A^{(\varphi_1+\varphi_2-1)} p_1^{-1} \varphi_1 \alpha X_z^{\varphi_3} \left(1 - \theta e^{-\lambda X_2}\right) \right]^{(1-\varphi_1)^{-1}} \tag{7}$$

$$X_2^{*A} = (\lambda A)^{-1}(lnP + ln\lambda + ln\theta + ln\alpha + \varphi_1 lnX_1 + \varphi_2 lnA + \varphi_3 lnX_Z - lnp_2) \tag{8}$$

Given that $G(\cdot) = 1 - e^{-\lambda X_2} \in [0,1]$ and $\theta \in [0,1]$, we obtain $\left(1 - \theta e^{-\lambda X_2}\right) \in [0,1]$. Assuming positive values for the variables P, p_A, X_1, X_z, A, p_1, and for the parameters $(1-\varphi_1)$, φ_1, $(1-\varphi_2)$, φ_2, α, and λ, the relationship between domestic grain price and the optimum land area and agrochemical use per unit of land can be derived: $\frac{\partial A^*}{\partial P} > 0$, $\frac{\partial X_1^{*A}}{\partial P} > 0$, and $\frac{\partial X_2^{*A}}{\partial P} > 0$. This gives the following two hypotheses:

Hypothesis 2. *The grain price received by a household positively affects the area sown with grain by that household.*

Hypothesis 3. *The grain price received by a household positively affects the use of agrochemicals per unit of land by that household.*

Following Benjamin [37], by assuming a Cobb–Douglas production function with constant returns to scale and assuming a relationship between farm size and the (shadow) price of agrochemicals in imperfect markets,

$$p_1 = d_1 A^{\rho_1} \tag{9}$$

$$p_2 = d_2 A^{\rho_2} \tag{10}$$

The relationship between agrochemical use per unit of land and land area can be derived, after substituting Equation (9) into Equation (7) and Equation (10) into Equation (8):

$$\frac{\partial X_1^{*A}}{\partial A} = (\varphi_1 + \varphi_2 - 1 - \rho_1)(1 - \varphi_1)^{-1} A^{\left(\frac{2\varphi_1 + \varphi_2 - 2 - \rho_1}{1 - \varphi_1}\right)} \left[d_1^{-1} \varphi_1 \alpha X_z^{\varphi_3} \left(1 - \theta e^{-\lambda X_2}\right) P \right]^{(1-\varphi_1)^{-1}} \tag{11}$$

$$\frac{\partial X_2^{*A}}{\partial A} = -(\lambda^{-1} A^{-2}) \left(lnP\lambda\theta\alpha d_2^{-1} X_1^{\varphi_1} A^{\varphi_2 - \rho_2} X_z^{\varphi_3} - \varphi_2 + \rho_2 \right) \tag{12}$$

Assuming positive values for the variables A, X_z, P and for the parameters $(1 - \varphi_1)$, d_1, φ_1, α, and $\left(1 - \theta e^{-\lambda X_2}\right)$ in Equation (11), the sign of $\frac{\partial X_1^{*A}}{\partial A}$ depends on $(\varphi_1 + \varphi_2 - 1 - \rho_1)$ and can in theory be either positive or negative. Empirical evidence indicates that generally it is negative (see e.g., [25,27,28,38]). Likewise, assuming that parameter λ and variable A are positive in Equation (12), the sign of $\frac{\partial X_2^{*A}}{\partial A}$ depends on $-\left(lnP\lambda\theta\alpha d_2^{-1} X_1^{\varphi_1} A^{\varphi_2 - \rho_2} X_z^{\varphi_3} - \varphi_2 + \rho_2 \right)$ and can in theory be either positive or negative. Empirical studies such as Nie et al. [25], Wu et al. [27], and Ren et al. [28], suggest that it is generally negative.

Note that if lower amounts of agrochemicals were used for non-grain crops planted before wheat or rice was grown on it, a switch towards planting grain crops will imply higher agrochemical use. This 'crop switching effect' is not considered in our mathematical model. Hence, taken together, the impact of land area sown with grain can in theory either be positive or negative. This gives the following hypotheses:

Hypothesis 4a. *The area sown with grain positively affects agrochemical use per unit of land.*

Hypothesis 4b. *The area sown with grain negatively affects agrochemical use per unit of land.*

The theoretical model analyzed above is presented schematically in Figure 1. The higher grain price that results from the minimum grain procurement price policy increases the profitability of grain and is thereby expected to increase the use of agrochemicals per unit of land. However, the price increase will also induce farmers to use more land for growing grain, which may either increase or reduce the use of agrochemicals per unit of land. Empirical research is needed to provide quantitative estimates of the sign (positive or negative) and magnitude of the net effect of these two counteracting forces.

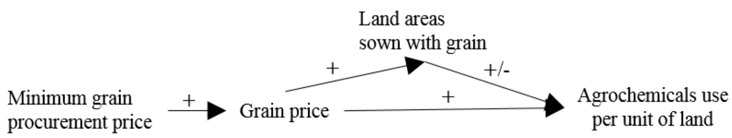

Figure 1. Theoretical framework.

3.2. Estimation Model Specification

In order to test the hypotheses developed in Section 3.1, we build a model consisting of three equations that can be used to estimate step by step the relationships shown in Figure 1. First, the price model in Equation (13) aims to examine the impact of the minimum grain procurement price on the grain price that rural households received. Second, the area model specified in Equation (14) intends to examine the impact of the grain (procurement) price on the area sown with grain. Following Nerlove [39,40] and Nerlove and Bessler [41], we account for possible time lags in area responses to price changes by including the one-period lagged land area. Third, the agrochemicals model in Equation (15) aims to estimate the impacts of the grain (procurement) price and the land area sown with grain on agrochemical use.

$$P_{G,it} = \alpha_{G1}PM_{G,it} + \alpha_{G2}D_{G,it} * PM_{G,it} + \alpha_{G3}WP_{G,t} + \alpha_{G4}sun_t + \alpha_{G5}pre_t + \alpha_{G6}tem_t + \mu_i + \varepsilon_{G,it} \quad (13)$$

$$A_{G,it} = \beta_{G1}P_{G,it-1} + \beta_{G2}\Delta PM_{G,it} + \beta_{G3}D_{G,it} * \Delta PM_{G,it} + \beta_{G4}A_{G,it-1} + \beta_{G5}con_{it} + \mu'_i + \lambda'_t + \varepsilon'_{G,it} \quad (14)$$

$$X^A_{C,it} = \sum_{G=W,R}(\gamma_{GC1}P_{G,it-1} + \gamma_{GC2}\Delta PM_{G,it} + \gamma_{GC3}D_{G,it} * \Delta PM_{G,it} + \gamma_{GC4}A_{G,it}) + \sum_{C=1,2}\gamma_{C5}p_{C,it} + \gamma_{C6}con_{it} + \mu''_i + \lambda''_t + \varepsilon''_{C,it} \quad (15)$$

The index G represents the type of grain (either W = wheat, or R = rice), while the index C represents the type of agrochemical (either 1 = chemical fertilizer, or 2 = chemical pesticides); i and t indicate household and year, respectively, μ_i-μ''_i are the household fixed effects, λ'_t-λ''_t are the year fixed effects, α, β, and γ are sets of unknown coefficients, and $\varepsilon_{G,it}$-$\varepsilon''_{C,it}$ are error terms with standard properties.

The variable P represents the grain price that a household received, while PM indicates the minimum procurement price. The dummy variable D takes a value 1 if the household lives in a province that applied the minimum procurement price policy and 0 otherwise. Hence, the coefficient α_{G1} reflects the impact of PM on the grain price received by households in those provinces that did not implement the policy, while α_{G2} represents the extent to which the impact differs between provinces that implemented the policy and those that did not. The coefficient α_{G3} reflects the impact of world market price WP on the grain price. Year effects are not included due to their perfect correlation with WP and PM. Instead, sunshine (sun), precipitation (pre), temperature (tem) are included to reflect the impact of domestic supply factors on grain price. Hypothesis 1 is supported when α_{G1} is significantly positive or, in case α_{G1} does not differ significantly from zero, α_{G2} is significantly positive.

The variable A denotes the land areas sown with grain, i.e., wheat and rice respectively. We use two alternative measures for this variable, the sown area (in hectares) and the share of the grain in total sown area. Following a commonly used Nerlovian approach [17], the areas sown with wheat and rice are assumed to depend on the area sown with the same crop in the previous year and the expected price for the crop. Besides the price received in the previous season, it may be assumed that the change in the minimum grain procurement price between the previous year and the current year, ΔPM, will also influence the price that farmers expect to receive. Minimum procurement prices are announced before the start of the season, and hence ΔPM and $D * \Delta PM$ are likely to be taken into account by farmers in their decision making. Finally, con is a control variable, i.e., the price of maize—the third major grain crop in China—in the previous year. Hypothesis 2 is supported when the coefficient β_{G1} is positive and significantly different from zero.

The variable X^{A} represents the use of agrochemicals, i.e., fertilizer and pesticides respectively, per hectare of cultivated land. It is assumed to depend on the expected grain price, proxied by the grain price in the previous year P, ΔPM and $D * \Delta PM$, on the price of the agrochemicals p in year t, and on the land areas sown with the two grains A in the current year. The control variable con is the same as in Equation (14). Hypothesis 3 is supported when the estimated coefficient γ_{GC1} is significantly positive, while Hypothesis 4a and Hypothesis 4b are supported when γ_{GC4} is significantly positive or negative, respectively.

3.3. Data

We use a large-scale household-level panel data set, the Rural Fixed Observation Points (RFOP) survey data set, covering the period 1997–2010, to estimate the model presented in Equations (13)–(15). The RFOP is a nationwide longitudinal data set collected by the Research Center for Rural Economy (RCRE) of the Ministry of Agriculture [25,42,43]. It annually covers more than 20,000 rural households living in more than 300 villages in 31 provincial-level administrative units [43]. The sampling method of the RFOP is as follows: to represent national rural development, different weights were allocated at the province-level according to the number of villages and their topographic and economic characteristics; then 3 to 25 villages were selected in each province-level unit, and households were randomly selected in each village [42]. The surveyed households are revisited annually, and information on household characteristics, land use, fixed assets, agricultural production, income, expenditure, etc. is recorded with the help of survey assistants [25,42]. The first survey was held in 1986, and it has been conducted each year since then except for 1992 and 1994 [25]. If a household left the village due to migration, a similar household was chosen to stabilize the sample size [42]. RFOP's panel nature allows us to track the changes in grain price, land areas sown with grain, and agrochemical use of households over time. We had access to the RFOP data for all years until 2010, so our analysis covers the eight/nine years before the introduction of the minimum procurement price program and the first five/six years after its introduction. We do not include the year before 1997, because Chongqing was still part of Sichuan at that time.

Information on minimum grain prices, weather conditions and world grain price indices was obtained from official statistics. Using the information provided in Table 1, the indicator of the minimum wheat procurement price (*PMW*) used in the empirical analysis was simply calculated as the mean value of the officially applied minimum prices of the three subspecies of wheat. The indicator of the minimum rice procurement price (*PMR*) was calculated in a similar manner, i.e., as the mean value of the officially applied minimum prices of mid/late Indica rice and Japonica rice; the price for early Indica rice was not included, because its minimum price was applied in a few provinces only (see Table 1). Data on weather conditions are only available for the capital city of each province. We assume that these city-level data are representative for the entire province.

Table 2 provides an overview of the mean values in each year of all variables used in the empirical analysis. Average chemical fertilizer use per hectare shows a fluctuating but increasing trend over time, with a total increase of 21% over the entire period. Pesticides use per hectare increased more rapidly, with the average value in 2010 equal to more than twice the value in 1997. Interestingly, the wheat and rice sown areas show a decreasing trend before 2004/2005, then they slightly increased for wheat and first increased but then declined again for rice. The average grain prices that households received decreased before 2003 but steadily increased after 2004 and coincided with the fluctuating but increasing average applied minimum grain prices. In the Appendix A, we provide a chart showing the time trends in the average wheat and rice prices (Figure A1).

Table 2. Mean values of variables used in empirical analysis.

	1997	1998	1999	2000	2001	2002	2003 [a]	2004	2005	2006	2007	2008	2009	2010
Fertilizer use (kg/ha)	903.88	900.13	900.04	917.58	901.21	949.60	1028.46	1006.00	963.93	991.37	1026.04	956.08	1054.37	1094.22
Pesticides use (kg/ha)	9.07	9.79	10.35	10.88	11.51	12.40	14.39	16.07	17.40	18.47	17.40	17.22	17.40	18.28
Wheat price (yuan/kg)	1.35	1.34	1.22	0.96	1.02	0.99	.	1.39	1.32	1.35	1.36	1.42	1.48	1.65
Rice price (yuan/kg)	1.42	1.53	1.24	1.12	1.24	1.11	.	1.56	1.63	1.56	1.74	1.76	1.69	1.99
Wheat-sown area [b] (ha)	0.14	0.13	0.14	0.13	0.12	0.11	0.09	0.07	0.07	0.08	0.09	0.09	0.09	0.09
Rice-sown area [b] (ha)	0.19	0.18	0.19	0.17	0.16	0.15	0.14	0.16	0.17	0.16	0.14	0.13	0.14	0.13
Share of wheat-sown area (%)	18.44	17.21	16.83	16.16	15.01	15.04	14.33	10.51	11.03	11.27	13.59	13.79	13.38	13.22
Share of rice-sown area (%)	28.07	27.70	27.95	27.08	26.12	25.79	25.51	28.07	28.00	26.73	23.54	22.02	23.14	21.50
Fertilizer price (yuan/kg)	1.37	1.27	1.22	1.13	1.10	1.12	1.18	1.31	1.51	1.52	1.56	1.94	1.76	1.75
Pesticides price (yuan/kg)	23.09	22.00	22.79	22.44	21.28	20.51	21.43	22.69	24.38	24.91	26.86	28.34	30.25	31.24
Maize price (yuan/kg)	1.18	1.22	1.09	1.01	0.98	1.02	.	1.20	1.14	1.22	1.41	1.27	1.39	1.95
Minimum price wheat (PMW, yuan/kg)	0	0	0	0	0	0	0	0	0	1.31	1.25	1.18	1.44	1.44
Minimum price rice (PMR, yuan/kg)	0	0	0	0	0	0	0	0	1.39	1.37	1.31	1.35	1.58	1.64
Dummy for PMW province (DW)	0	0	0	0	0	0	0	0	0	0.34	0.27	0.28	0.28	0.28
Dummy for PMR province (DR)	0	0	0	0	0	0	0	0	0.39	0.39	0.32	0.49	0.51	0.51
Change in PMW (ΔPMW, yuan/kg) [c]	0	0	0	0	0	0	0	0	0	0	−0.06	−0.07	0.26	0
Change in PMR (ΔPMR, yuan/kg) [c]	0	0	0	0	0	0	0	0	0	−0.02	−0.06	0.04	0.23	0.06
Annual total sunshine (×100 h)	19.55	19.07	18.92	18.70	19.42	18.46	18.17	19.98	18.67	18.55	19.05	19.45	19.37	18.95
Annual total precipitation (×100 m)	8.89	10.40	9.60	8.98	8.72	9.44	10.00	9.18	10.13	9.46	8.07	9.42	8.88	10.34
Annual average temperature (degrees Celsius)	14.26	14.93	14.33	14.06	14.34	14.53	14.23	14.53	14.11	14.72	14.93	14.32	14.45	14.08
World wheat price index (1997 = 100)	100	75.38	63.31	62.80	64.48	78.87	76.96	76.37	71.28	90.06	119.69	146.07	96.12	96.11
World rice price index (1997 = 100)	100	99.56	85.65	73.94	63.69	62.37	70.13	85.94	90.04	95.75	116.11	204.10	158.71	159.30

Notes: [a] Crop price information is missing in 2003 in the Rural Fixed Observation Points (RFOP) data set; All price variables have been deflated to 1997 prices, using national consumer price index data.
[b] Mis-recordings of sown areas were identified by comparing its data for the same household for different years. We corrected those mis-recorded data multiplying them by (various dimensions) of 0.1 or 10.
[c] The value of ΔPM is assumed to be zero during the years before the start of the procurement price program and the year when it started. Source: RFOP survey data set and [3,29,44,45].

3.4. Estimation Method

Difference-in-differences (DID) is the most frequently used impact evaluation method in non-experimental settings when before-after and treatment-control group data are available. Applying DID hinges upon several assumptions, with the "parallel trends" assumption being the most important one [46]. The data set that we used for this study is suitable for applying DID, given that we have rural households before and after the minimum grain procurement price program was implemented and households in a treatment group (designated provinces) and in a control group (other provinces). But unfortunately, the two main outcome variables (i.e., chemical fertilizer and pesticides use per hectare of land) do not satisfy the "parallel trends" assumption (see Figures A2 and A3 in Appendix A). Instead, we follow other studies examining the effect of the major subsidy programs on rural household production decisions in applying multiple regression panel data analysis [42,47].

Previous studies using the panel data sets to examine the driving forces of sown areas and agrochemical use, Nie et al. [25], Wu et al. [27], Yi et al. [42], and Gao et al. [43], applied fixed effect regressions to control for potential endogeneity problems caused by unobserved time-invariant household-specific variables. Likewise, we apply fixed effect regression in this study to estimate Equations (13) and (15). The dynamic nature of Equation (14), caused by the lagged A variable leads to biased and inconsistent OLS estimators [48]. To solve this problem, we follow Yu and You [49] and apply the difference generalized methods of moments (GMM) regression to estimate Equation (14).

4. Results and Discussion

In this section, we first present and discuss the regression results for each of the three equations specified in Section 3.2. Based on these estimates, we present an integrated assessment of the effects of the observed changes in minimum grain procurement prices during the period 2005/2006–2010 at the end of the section.

4.1. Grain Price

The fixed effects regression results obtained for wheat and rice prices, based on Equation (13), are summarized in Table 3. Columns (1) and (2) in Table 3 present the results for the wheat price, and columns (3) and (4) for the rice price.

Table 3. Fixed effects regression results for wheat and rice price.

	Wheat Price		Rice Price	
	(1)	(2)	(3)	(4)
	Coefficient	SE	Coefficient	SE
Minimum price wheat (PMW)	0.147 ***	(0.002)	-	-
Dummy for PMW province (DW) * PMW	−0.001	(0.002)	-	-
Minimum price rice (PMR)	-	-	0.218 ***	(0.002)
Dummy for PMR province (DR) * PMR	-	-	−0.037 ***	(0.003)
World wheat price (WPW)	0.146 ***	(0.005)	-	-
World rice price (WPR)	-	-	0.262 ***	(0.004)
Annual total sunshine (sun)	0.030 ***	(0.001)	0.009 ***	(0.001)
Annual total precipitation (pre)	0.020 ***	(0.000)	0.007 ***	(0.000)
Annual average temperature (tem)	−0.026 ***	(0.001)	0.003	(0.002)
Household fixed effects	Yes		Yes	
Observations	191,439		234,810	
R^2	0.150		0.194	

Note: Household clustered standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; World wheat price index and World rice price index were divided by 100.

As expected, the minimum procurement prices positively affect the wheat and rice prices that households received. This finding provides support for Hypothesis 1 postulated in Section 3.1, and is consistent with the results obtained in Qian et al. [12]. We further find that the positive effect of the minimum procurement price for wheat does not differ significantly between provinces that implemented the policy and provinces that did not implement it, suggesting that wheat markets in the country are highly integrated. Keeping other factors constant, an increase in the minimum price for wheat of 0.10 yuan/kg is found to increase the wheat price that farmers receive by 0.015 yuan/kg. For rice, we find that the impact of the minimum procurement price is slightly higher in provinces that did not implement the program. Keeping other factors fixed, these estimates indicate that an increase in the minimum price for rice of 0.10 yuan/kg increases the rice price by 0.018 yuan/kg in provinces that implemented the program and by 0.022 yuan/kg in provinces that did not implement it. The reason for this difference remains unclear and needs further research. As expected, the world market prices of wheat and rice significantly affect the domestic prices of these crops, which is consistent with the findings in Li et al. [7] for China's wheat market. We further find that the estimated effect of the world market price is considerably larger for rice than for wheat.

4.2. Land Areas Sown with Grain

The difference GMM estimation results for land areas sown with grain, based on Equation (14), are summarized in Table 4. Column (1) presents the results for wheat area and column (2) for rice area; results for the shares of land sown with wheat and rice are shown in columns (3) and (4).

As expected, the wheat and rice prices positively affect the land areas sown with wheat and rice, respectively. This finding provides support for Hypothesis 2 (see Section 3.1). Similar results were found by Mushtaqa and Dawson [11] for cotton, sugarcane and high yielding variety rice in Pakistan, by Bayramoglu and Chakir [19] for rapeseed in France, by Siad et al. [50] for durum wheat in Italy, and by Wang et al. [51] and Lu [52] for wheat, maize, and rice in three Chinese provinces, i.e., Zhejiang, Shandong, and Henan. The price elasticity of the wheat sown area equals 0.560, while the price elasticity for rice sown area equals 0.943 (see Table A1 in Appendix A). The impact of the wheat area in the previous year does not differ significantly from zero, which indicates that wheat farmers respond instantaneously to price changes. Responses of rice farmers are less prompt, given the significant coefficient estimate for the lagged rice area. The estimated long-term price elasticity of rice sown area equals 1.274 (see Table A1).

As argued in Section 3.2, we assume that expected prices depend at least partly on the minimum procurement prices which are announced before the start of the growing season. The estimation results in Table 4 confirm that these procurement prices positively affect the land areas sown with wheat and rice. This is consistent with the findings in Ali et al. [20], Krishnaswamy [22], and Ritu et al. [24] for India, and Li et al. [7] and Qian et al. [12] for China. Estimated elasticities equal 0.009 for wheat and 0.049 for rice (see Table A1). The impact of the minimum procurement prices does not differ significantly between provinces that implemented the policies and those that did not, except for the share of land sown with rice. This finding seems to indicate that price expectations do not differ much between the two groups of provinces due to the high degree of integration in wheat and rice markets in China.

Table 4. Difference generalized methods of moments (GMM) regression results for sown land areas.

Outcome Variables	Land Area (ha)		Share of Land (%)	
	Wheat	Rice	Wheat	Rice
	(1)	(2)	(3)	(4)
One-period lagged wheat-sown area ($AreaW_{t-1}$)	0.215 (0.134)	- -	- -	- -
One-period lagged rice-sown area ($AreaR_{t-1}$)	- -	0.285 *** (0.062)	- -	- -
One-period lagged wheat-sown area share ($AreaW_{t-1}$)	- -	- -	0.048 (0.037)	- -
One-period lagged rice-sown area share ($AreaR_{t-1}$)	- -	- -	- -	0.040 *** (0.014)
Wheat price ($PriceW_{t-1}$)	0.112 ** (0.044)	- -	9.090 *** (0.921)	- -
Rice price ($PriceR_{t-1}$)	- -	0.116 ** (0.046)	- -	7.836 *** (1.281)
Change in minimum price wheat (ΔPMW)	0.168 *** (0.028)	- -	6.897 *** (1.272)	- -
Dummy for PMW province (DW) * ΔPMW	−0.000 (0.010)	- -	0.240 (0.270)	- -
Change in minimum price rice (ΔPMR)	- -	0.328 *** (0.052)	- -	34.911 *** (2.874)
Dummy for PMR province (DR) * ΔPMR	- -	0.006 (0.015)	- -	−3.745 *** (0.824)
Maize price, year $_{t-1}$	0.067 * (0.039)	−0.024 (0.041)	−0.461 (0.914)	1.268 (1.370)
Observations	94,778	105,591	94,778	105,589
AR(1) test *p*-value	0.000	0.000	0.000	0.000
AR(2) test *p*-value	0.056	0.143	0.031	0.688

Note: Robust standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.3. Agrochemical Use

Fixed effects regression results for agrochemical use, based on Equation (15), are summarized in Table 5. Column (1) presents the results for fertilizer and column (2) for pesticides; columns (3) and (4) present the results when the sown land areas are replaced by the shares of land sown with wheat and rice.

The main finding is that the prices of wheat and rice positively affect both chemical fertilizer use and pesticides use. Hence, we find empirical support for Hypothesis 3 in the case of fertilizer as well as pesticides. It is consistent with results obtained by Heerink et al. [5] for Jiangxi province in China and Bayramoglu and Chakir [19] for France. The elasticities that correspond to the estimated coefficients are presented in Table A2 in Appendix A. They indicate that fertilizer use is slightly more responsive to wheat and rice prices than pesticides use.

As expected, the change in the minimum procurement price of wheat between the current year and the previous year has a significant positive impact on the use of both types of agrochemical. For pesticides use, the impact is somewhat larger in provinces where the program was implemented, whereas the impact is not significantly different between the two groups of provinces for fertilizer use. For the minimum rice procurement price, however, we find negative instead of positive effects. This finding conflicts with a priori expectations derived from theory. A possible explanation is that rice farmers are willing to take more risk when the minimum rice procurement price increases, and rely more on organic fertilizer and biological pest control methods for increasing yields. More research is needed to examine this conjecture.

Table 5. Fixed effects regression results for agrochemical use.

Outcome Variables	**Fertilizer Use (kg/ha)**	**Pesticides Use (kg/ha)**	**Fertilizer Use (kg/ha)**	**Pesticides Use (kg/ha)**
	(1)	**(2)**	**(3)**	**(4)**
Wheat price ($PriceW_{t-1}$)	31.874 *** (6.285)	0.308 ** (0.143)	33.238 *** (6.382)	0.342 ** (0.143)
Rice price ($PriceR_{t-1}$)	26.029 *** (5.042)	0.367 *** (0.112)	28.171 *** (5.081)	0.420 *** (0.113)
Change in minimum price wheat (ΔPMW)	1771.208 *** (176.246)	45.606 *** (4.290)	1711.530 *** (175.853)	44.491 *** (4.266)
Dummy for PMW province (DW) * ΔPMW	−28.713 (64.388)	4.036 *** (1.515)	−39.027 (63.777)	3.858 *** (1.494)
Change in minimum price rice (ΔPMR)	−2612.994 *** (308.339)	−73.951 *** (7.275)	−2538.162 *** (307.070)	−73.000 *** (7.219)
Dummy for PMR province (DR) * ΔPMR	−445.303 *** (82.597)	−3.615 ** (1.783)	−389.970 *** (81.557)	−1.672 (1.760)
Wheat-sown area (AreaW)	−239.801 *** (15.062)	−4.298 *** (0.328)	- -	- -
Rice-sown area (AreaR)	−102.024 *** (12.001)	−2.301 *** (0.326)	- -	- -
Wheat-sown land share (AreaW)	- -	- -	−5.095 *** (0281)	−0.148 *** (0.006)
Rice-sown land share (AreaR)	- -	- -	−0.198 (0.195)	0.023 *** (0.005)
ln (Fertilizer price)	−598.742 *** (12.028)	1.610 *** (0.173)	−602.962 *** (12.045)	1.561 *** (0.172)
ln (Pesticides price)	70.896 *** (5.173)	−10.772 *** (0.152)	66.978 *** (5.101)	−10.859 *** (0.152)
Maize price, year $_{t-1}$	22.030 ** (10.481)	0.068 (0.176)	23.492 ** (10.448)	0.133 (0.173)
Household fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	128,536	128,536	128,536	128,536
R^2	0.104	0.172	0.107	0.182

Note: Household clustered standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

With regard to the sown areas, we find significant negative effects of both the wheat sown area and the rice sown area on chemical fertilizer and pesticides use. These findings indicate that Hypothesis 4a should be rejected and provides support for Hypothesis 4b postulated in Section 3.1. They suggest that the negative relationship between land area and agrochemical use per unit of land found for China by Nie et al. [25], Wu et al. [27], Ren et al. [28], and for Nigeria by Rahman and Chima [53] also exists for individual grain crops. Interestingly, the estimated effect is stronger for the area sown with wheat as compared to the rice sown area, as can be seen from the elasticities presented in Table A2.

4.4. Integrated Assessment

As analyzed in Section 3.1, the minimum support price affects the grain price that households received and thereby affects the use of agrochemicals per hectare of land. The minimum grain procurement price also affects land for growing grain through expected grain crop price and then affects agrochemical use per unit of land. By respectively multiplying all the mediators' estimated coefficients in the two channels referred above and adding them, the total effects of the minimum grain procurement price program on the use of agrochemicals hence could be derived [54]. To this end, we use the changes in the (deflated) official minimum wheat and rice procurement prices from 2005/2006–2010 presented in Table 2, and combine them with the estimated coefficients presented in Tables 3 and 4 to derive the effects of these changes on the prices and sown areas of wheat and rice. The resulting effects are combined with the estimated coefficients presented in Table 5 and the mean annual changes in the minimum procurement prices to derive the effects presented in Table 6.

Table 6. Estimated effects for the provinces that implemented the minimum grain procurement price policy until 2010.

	Chemical Fertilizer		Chemical Pesticides	
	Coefficient	**Effect (kg/ha)**	**Coefficient**	**Effect (kg/ha)**
Wheat price ($PriceW_{t-1}$)	31.874	0.609	0.308	0.006
Rice price ($PriceR_{t-1}$)	26.029	1.178	0.367	0.017
Change in minimum price wheat (△PMW)	1771.208	46.051	45.606	1.186
Dummy for PMW province (DW) * △PMW	0	0	4.036	0.105
Change in minimum price rice (△PMR)	−2612.994	−108.875	−73.951	−3.081
Dummy for PMR province (DR) * △PMR	−445.303	−18.554	−3.615	−0.151
Wheat-sown area (AreaW)	−239.801	−5.751	−4.298	−0.103
Rice-sown area (AreaR)	−102.024	−9.011	−2.301	−0.203
Total	-	−94.352	-	−2.225

Note: Derived from coefficient estimates presented in Table 5, actual increases in minimum procurement prices for rice and estimated changes in wheat and rice prices and areas caused by these increases (only for the sown area instead of the share of the grain in total sown area).

The main conclusion is that, assuming other factors remained constant, the minimum procurement prices had negative effects on the use of chemical fertilizer and on the use of pesticides during the period 2005/2006–2010. For the provinces that implemented the policy, our calculations suggest that without the minimum grain procurement price program the use of fertilizer would have been 8.7% (=100 × 94.35/1094.22) higher in 2010, and the use of pesticides would have been 12.2% (=100 × 2.23/18.28) higher. Similarly, for the provinces that did not implement the policy, the use of fertilizer would have been 6.8% higher in 2010, and the use of pesticides would have been 11.77% higher, without the minimum grain procurement price program.

A closer look at the different effects presented in the table gives insight into their relative strengths. The positive effects of the minimum procurement prices on the prices of wheat and rice indeed stimulated larger use of the two agrochemicals, while the increases in the areas sown with wheat and rice that resulted from the procurement price program induced a lower use of agrochemicals per unit land. However, these two counteracting effects were overshadowed by the direct effects of the minimum procurement prices on the use of chemical fertilizer and pesticides. Higher minimum procurement prices lead to both higher expected output prices and to lower output price risk. We find that these direct effects stimulated the use of agrochemicals in the case of wheat procurement prices, but reduced the use of agrochemicals in the case of rice procurement prices, with the latter effect considerably outweighing the former. The net result of these different counteracting forces of higher minimum procurement prices were lower levels of chemical fertilizer and pesticides use (assuming other forces remained constant) than would have been the case without the program.

5. Conclusions

The aim of this study was to investigate whether and how China's minimum grain procurement price program affected rural households' agrochemical use. Using a large household-level data set that covers the years 1997–2010, we find that the program negatively affected both chemical fertilizer and pesticides use, with pesticides use being more responsive than the use of fertilizer. The dominating force that caused these negative effects is the direct impact of the minimum procurement price for rice on the use of chemical fertilizer and pesticides. The minimum procurement price for wheat, on the other hand, is found to stimulate the use of agrochemicals. But its effect was smaller than the effect of the minimum rice procurement price. The indirect effects through changes in market prices and changes in areas sown with the two crops are found to be relatively small.

In the empirical analysis, we made a distinction between provinces that were designated to implement the program and other provinces, but we found only very small or insignificant differences between the two groups. This finding confirms outcomes of earlier research showing that agricultural output markets in China are highly integrated [55,56].

Some important implications for policy-making can be drawn from these findings. First, it is essential to realize that the minimum grain procurement price policy has positive environmental effects by encouraging lower levels of chemical fertilizer and pesticides use in the case of rice, but negative environmental effects in the case of wheat. To some extent, the minimum price policy for wheat conflicts with recently introduced policies aimed at reducing agrochemical use in China. This points to the need for carefully designing and applying price intervention policies. Second, the mediating roles that the land areas sown with grain played in affecting agrochemical use per unit of land shows that farm size has a substantial influence on agricultural sustainability from the aspect of the environment. Addressing farm size and expanding large-scale operations can be an important way to promote sustainable agriculture, given the small farm sizes that are still dominant in Chinese agriculture. Considering that large-scale farming may increase the likelihood that pests and diseases occur, promoting large-scale operation should preferably be integrated with technological innovation and providing better information on pest control and prevention, including the use of biopesticides and options for integrated pest management.

Our study points to the need for further research in several ways. First, more research is needed to check the robustness of our finding that the minimum procurement price of rice negatively affects the use of chemical fertilizer and pesticides. In particular, researchers with access to the RFOP data from 2011 onwards should examine whether this crucial finding also holds for the later period in which the policy was implemented. Second, more insight is needed into the reasons why rice farmers use lower levels of agrochemicals when the minimum rice price announced at the start of the season is raised. Is it because farmers are willing to use more risky organic and biological inputs, or are there other reasons? Examining farmers' risk preferences when assessing the impacts of the minimum procurement price on agrochemical use may be a fruitful future research direction. Third, our measurements of fertilizer and pesticides use are not perfect, because detailed information on the use of agrochemicals in rice cultivation and in wheat cultivation is not available in the RFOP survey data set. Research based on more detailed data sets, e.g., including the use of organic fertilizer and biopesticides, is needed to obtain deeper insights into the impact of China's minimum grain procurement price program on rural households' agrochemical use.

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

Appendix A

Table A1. Estimated elasticities for sown land areas.

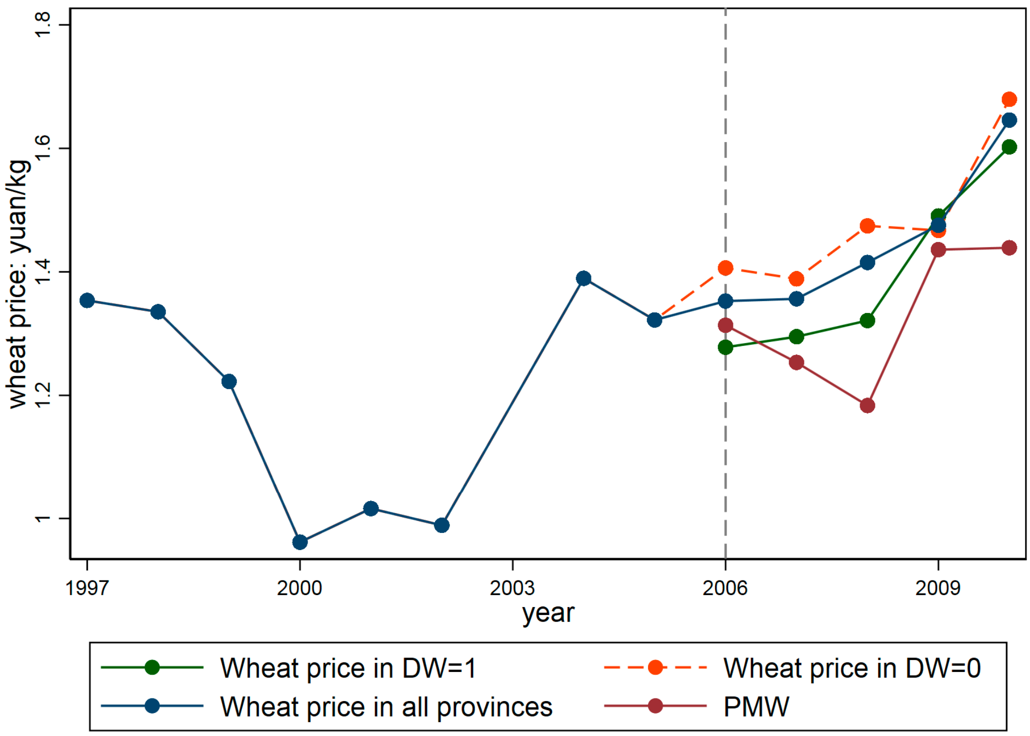
Outcome Variables	Sown Area (ha)		Share of Land (%)	
	Wheat	Rice	Wheat	Rice
	(1)	(2)	(3)	(4)
One-period lagged wheat-sown area	0.131 ** (0.065)	- -	- -	- -
One-period lagged rice-sown area	- -	0.260 ** (0.114)	- -	- -
One-period lagged share of wheat-sown area	- -	- -	0.084 (0.059)	- -
One-period lagged share of rice-sown area	- -	- -	- -	0.078 *** (0.027)
Wheat price	0.560 *** (0.150)	- -	0.972 *** (0.123)	- -
Rice price	- -	0.943 *** (0.261)	- -	0.876 *** (0.126)
Change in minimum price wheat (ΔPMW)	0.009 *** (0.002)	- -	0.008 *** (0.002)	- -
Change in minimum price rice (ΔPMR)	- -	0.049 ** (0.020)	- -	0.072 *** (0.010)
Long-run price elasticity	-	1.274	-	0.950

Note: Standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

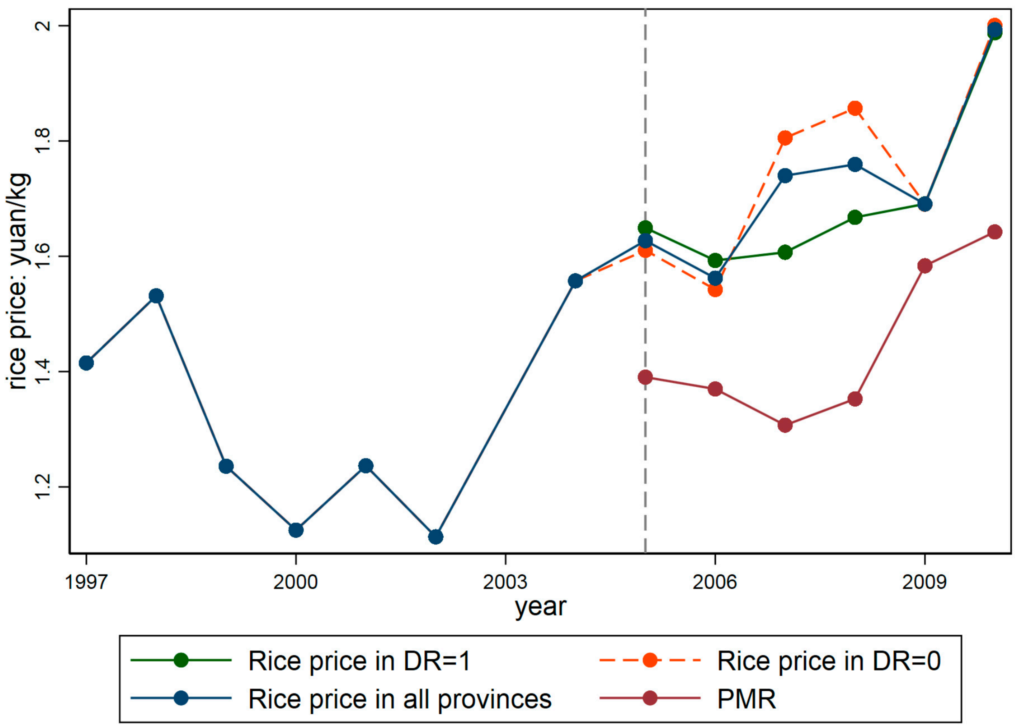
Table A2. Main estimated elasticities for agrochemical use.

Outcome Variables	Fertilizer Use (kg/ha)	Pesticides Use (kg/ha)	Fertilizer Use (kg/ha)	Pesticides Use (kg/ha)
	(1)	(2)	(3)	(4)
Wheat price ($PriceW_{t-1}$)	0.042 *** (0.008)	0.028 ** (0.013)	0.044 *** (0.008)	0.032 ** (0.013)
Rice price ($PriceR_{t-1}$)	0.039 *** (0.008)	0.039 *** (0.012)	0.043 *** (0.008)	0.045 *** (0.012)
Change in minimum price wheat (ΔPMW)	0.019 *** (0.002)	0.034 *** (0.003)	0.018 *** (0.002)	0.036 *** (0.003)
Dummy for PMW province (DW) * ΔPMW	−0.000 (0.000)	0.001 *** (0.000)	−0.000 (0.000)	0.001 *** (0.000)
Change in minimum price rice (ΔPMR)	−0.063 *** (0.007)	−0.124 *** (0.012)	−0.061 *** (0.007)	−0.123 *** (0.012)
Dummy for PMR province (DR) * ΔPMR	−0.005 *** (0.001)	−0.003 ** (0.002)	−0.005 *** (0.001)	−0.001 *** (0.002)
Wheat-sown area (AreaW)	−0.031 *** (0.002)	−0.039 *** (0.003)	- -	- -
Rice-sown area (AreaR)	−0.015 *** (0.002)	−0.024 *** (0.003)	- -	- -
Wheat-sown land share (AreaW)	- -	- -	−0.092 *** (0.005)	−0.187 *** (0.008)
Rice-sown land share (AreaR)	- -	- -	−0.005 (0.005)	0.038 *** (0.008)

Note: Standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

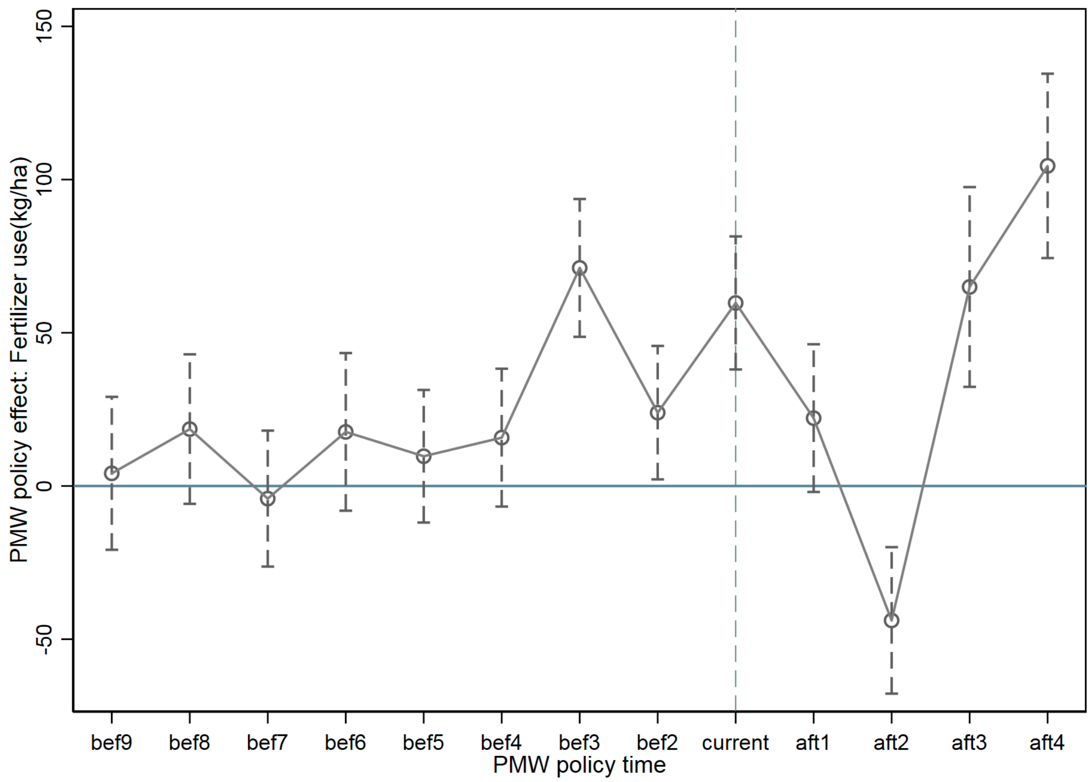


(**A**) Wheat price

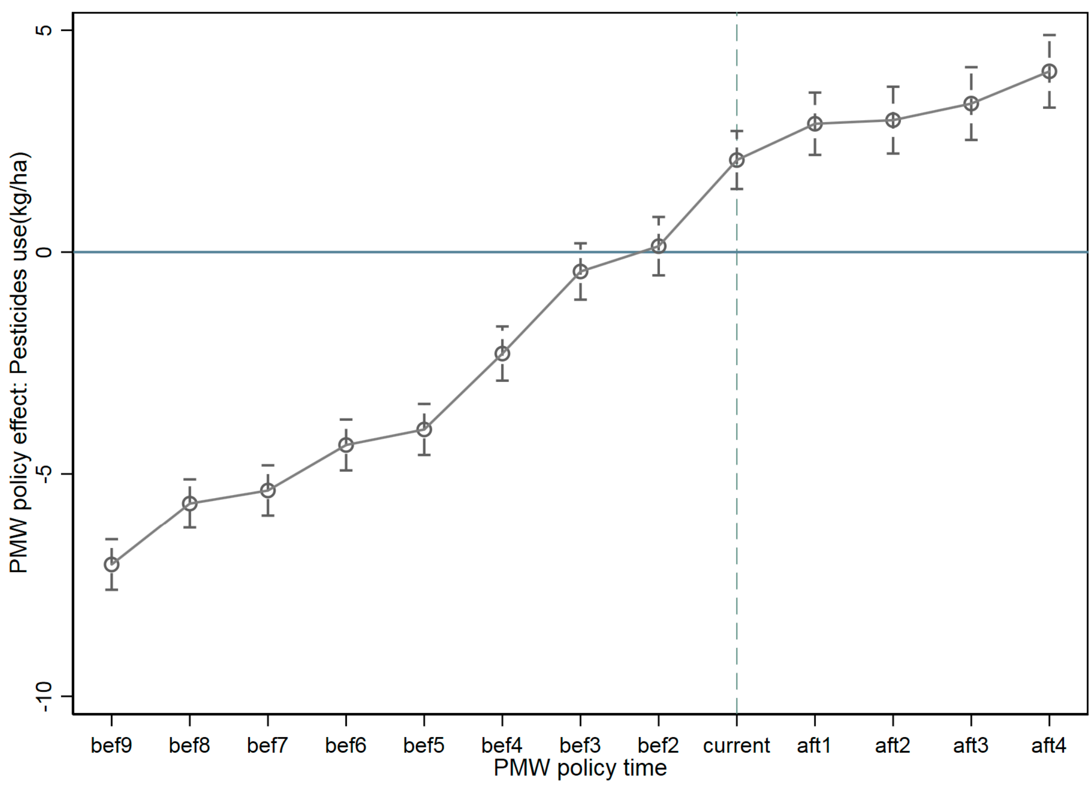


(**B**) Rice price

Figure A1. Trends of average price for (**A**) Wheat and (**B**) Rice; In yuan/kg; All prices have been deflated to 1997 prices, using national consumer price index data. Source: Calculated from the RFOP survey data set 1997–2010 combined with [3].

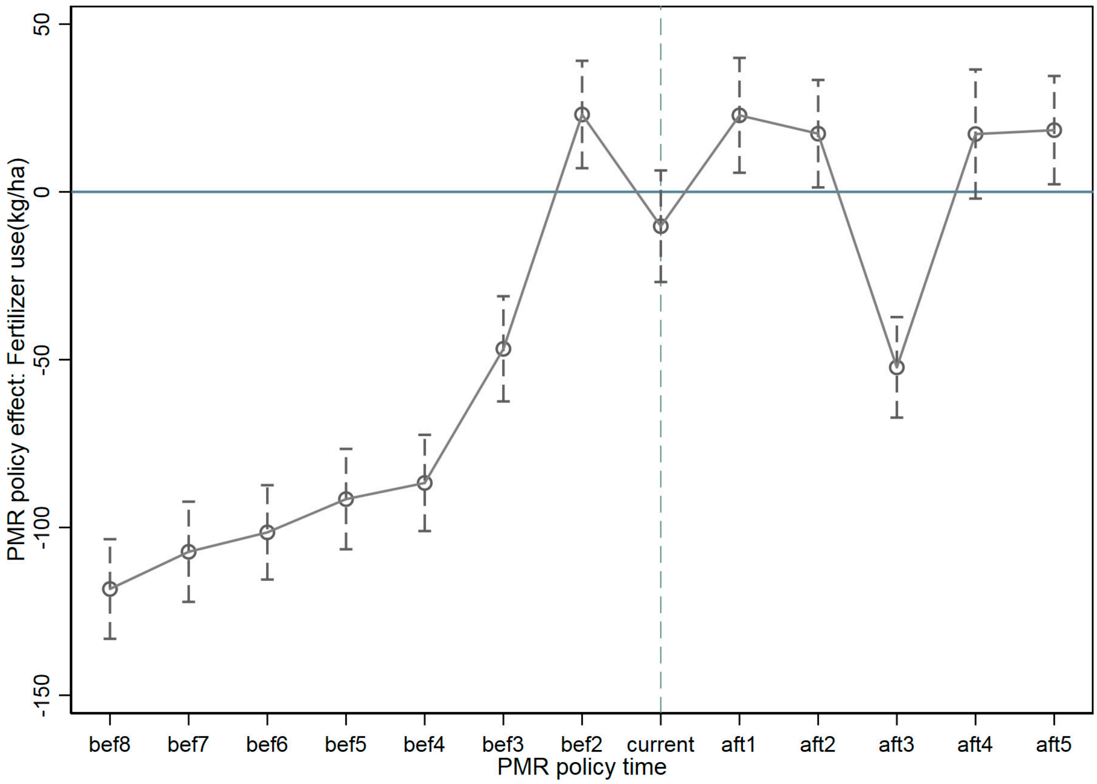


(**A**) Fertilizer

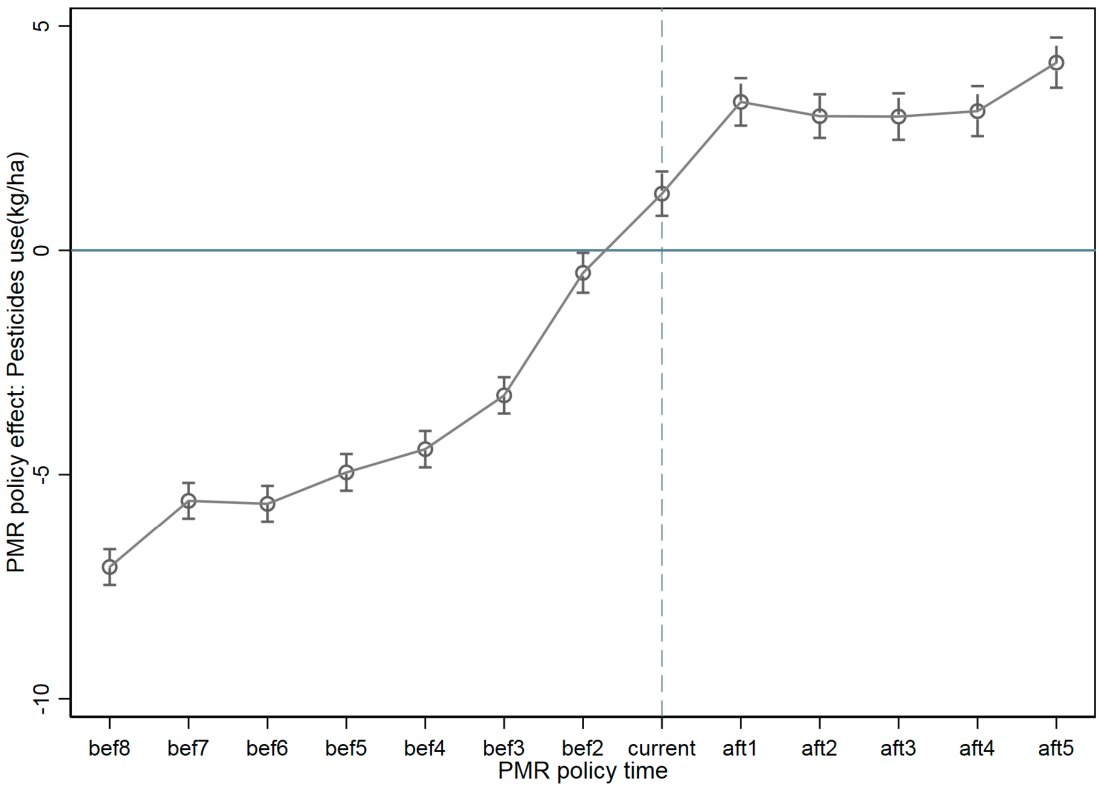


(**B**) Pesticides

Figure A2. Parallel trends of the *PMW* program for (**A**) Fertilizer and (**B**) Pesticides; In kg/ha; For a 95% confidence interval. Source: Calculated from the RFOP survey data set 1997–2010.



(**A**) Fertilizer



(**B**) Pesticides

Figure A3. Parallel trends of the *PMR* program for (**A**) Fertilizer and (**B**) Pesticides. In kg/ha; For a 95% confidence interval. Source: Calculated from the RFOP survey data set 1997–2010.

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