Production Risk and the Early Adoption of Alternatives to Antibiotics: Evidence From Poultry Farmers in China

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Abstract

Excessive or unreasonable use of agricultural chemicals has caused a wide range of negative effects on the environment and residents' health. It is urgent to promote the reduction of the use of agricultural chemicals. Taking the use of veterinary antibiotics (hereafter antibiotics) in broiler breeding as an example, based on the data of 380 contract farmers, this paper first investigated the effects of production risk on farmers' decision-making on the use of alternatives to antibiotics and the amount of antibiotics in the initial stage of alternatives entering into the market. The results show that: (1) the fluctuation of mortality in the lag period has no significant influence on the adoption of alternatives, and farmers are concerned about the absolute or average level of mortality in the lag period. (2) The mortality rate lagged three phases had a significant positive impact on the adoption of alternatives. On average, the mortality rate lagged three phases increased by 0.01, and the likelihood of farmers adopting substitutes in the early stage increased by 0.670%. (3) The production risk plays an important role in regulating the effects of alternatives. When using alternatives, the mortality rate of lagging three phases is higher, the higher the dosage of antibiotics and the lower the mortality rate in the early stage, suggesting that higher production risk would result in using alternatives for the purpose of reducing the production risk rather than reducing the use of antibiotics. Thus, to realize the effect of alternatives in reducing agricultural chemicals, the prerequisite is to improve the production risk management ability of farmers.

1. Introduction

Over the past decades, the extensive use of veterinary antibiotics has brought myriad threats to ecological safety and human health. China is one of the largest users of veterinary antibiotics. A state report published in 2019 reveals that the total amount of antibiotics used in animal breeding in 2016 was 44,185.75 tons, and without any effective control, antibiotics consumption in livestock animals is expected to grow exponentially (Tiseo et al., 2020). Almost 53.2% of antibiotics in China are used to promote growth, which is one of the main reasons for the increased incidents of drug-resistance bacteria (DRB) that are dangerous for human health (Zhang et al., 2017). DRB can be transferred to the human body through live animals, animal products, and water and soil contaminated (Sarmah et al., 2006; Kemper, 2008), resulting in increased health risks due to the weakening antibacterial effect of antibiotics for human use (Burbee et al., 1985; Laxminarayan, 2001). To legitimate the use of antibiotics, China has initiated a Pilot Action Plan in 2018 and organized more than 100 large-scale breeding farms to carry out the pilot work.

A broader trajectory towards sustainable agriculture through uptake of biological pesticides, green additives and other alternatives to agricultural chemicals can reduce the use of dangerous chemicals. Several studies have explored the determinants of farmers' adoption of alternatives. Inter alia, peers' behavior (Zhou et al., 2019), farmers' education level (Abdollahzadeh et al., 2015), production experience (Moser et al., 2008), risk preference (Gao et al., 2017), and cognitions on technologies (Abdollahzadeh et al., 2015; Khan and Damalas, 2015) have been documented to have a significant impact on farmers' adoption of alternatives. While production risk has a significant role in the uptake of antibiotics, there

remain major knowledge gaps about whether and how it affects poultry farmers' behavior in adopting new technologies. To this end, exploring the role of production risk will help unfold the process and how farmers tend to adopt sustainable alternatives in poultry production in China.

Many researchers argue that increased use of sustainable alternatives does not mean a lower amount of agricultural chemicals. For example, Yee & Ferguson (1996) found that although integrated pest management was somewhat effective in controlling crop pests, it was potentially ineffective in reducing pesticide use at a broader scale. Why can such alternatives not reduce agricultural chemicals? This requires a clear understanding of farmers' motives for using alternatives. Agricultural chemicals and their alternatives are damage control inputs (Lichtenberg and Zilberman, 1986). Damage is usually associated with production risk. Even if a large number of agricultural chemicals are used, farmers still face certain production risks. In this case, farmers may use alternatives to reduce production risk rather than reducing production costs while maintaining production risk. In other words, production risk may be the key driver of loss of the substitute effect of alternatives to damage-control inputs. However, little is known about farmers' decisions on adopting alternatives and reducing agricultural chemicals from a production risk perspective.

In cross-sectional data, the relationship between production risk and the use of agricultural chemicals or their alternatives is often endogenous. Existing studies have ignored this problem, but this study effectively addresses this problem by using a unique data set. In this study, the input-output data of farmers contracting with a broiler breeding company were obtained. To follow government regulations to legitimate antibiotics, the local companies have started supplying farmers with alternatives to antibiotics. This study traces farmers' adoption of alternatives back to the initial stage when alternatives entered the market, that is, when companies supplied substitutes to farmers. At this point, the production risk is completely unrelated to the experience of alternatives use, making the study findings more reliable in terms of endogeneity issues.

To sum up, this study uses a data set of poultry contract farmers' adoption of alternatives at the early stage of alternatives entering the market and their previous performance. Given these, this research tries to answer the three questions. First, at the beginning of alternatives entering the market, how does the production risk affect farmers' decision to use alternatives? Second, does the use of alternatives reduce poultry antibiotics? Third, how does production risk work on the effect of alternatives use? By stabilizing the understanding on these questions, this study would contribute to the literature in mainly three aspects. First, it will unfold the nature of the relationship – substitute or complement – between agricultural chemicals and their alternatives from the production risk perspective. It builds on how farmers use the alternatives to antibiotics as substitutes. Second, this study is the pioneer by systematically investigating production risk's role in the decision and effect of substitution adoption. Third, a novel approach – based on lagged mortality rate various indexes were used – was adopted to measure the production risk, and the differential effects of the average mortality rate and the fluctuation of mortality rate were compared. This study contributes to a deeper understanding of farmers' behavioral decisions and provides implications for promoting sustainable alternatives to reduce antibiotics use in poultry.

The following arrangements are as follows. The second part reviews the literature; the third part introduces the econometric model, data and variables; the fourth part reports and discusses the empirical results; the last part summarizes the findings and puts forward suggestions.

2. Literature Review

Agricultural economists have paid close attention to production risk for a long time. Komarek et al. (2020) reviewed 3,283 studies related to agricultural risks published between 1974 and 2019 and found that 66% of the studies focused solely on production risk. In the academic circle, it has become a consensus that farmers use large quantities of agricultural chemicals to avoid production risk. Existing studies mainly verify this judgment by assessing the impact of risk attitude on the amount of agricultural chemicals, and representative studies include Liu & Huang (2013) and Gong et al. (2016). These studies obtained farmers' risk preference through experimental methods and reached the consistent conclusion that the more risk avoidance of farmers, the higher the amount of agricultural chemicals.

A more direct causal relationship is the impact of production risk faced by farmers on their use of agricultural chemicals. Production risk is difficult to observe because they are always related to adverse events that have not yet occurred and are merely hypothetical (Hardaker, 2016). Some studies have chosen to investigate the impact of production risk perception on farmers' risk management behavior. For example, Riwthong et al. (2017) used the 5-Point Likert scale to measure farmers' perception of production risk. The study found that farmers thought crop pests and diseases were the most serious production risks, and the higher the commercialization level of farmers, the more likely they were to use pesticides in large quantities to overcome the risk of pests and diseases.

Existing studies exhibit inconclusiveness, such as subjectivity and strong endogeneity in using production risk perception to characterize production risk. Some scholars use historical data to represent production risk in the current or the future. The earliest representative study was Anderson and Griffiths (1982), which examined the effect of mean and variance of crop yield on production inputs. Although the future may be more uncertain than the past, the historical frequency can be used to indicate the probability of future risk. The implied assumption is that risk is stable in the past and the future and that there are no leaps in it (Hardaker, 2016). Limited by the availability of data, analysis based on historical data focuses on the production risks caused by changes or fluctuations in temperature and rainfall at the regional level (e.g., Kingwell and Farre, 2009). In general, any indicator of risk is inevitably subjective, but the academic consensus is higher on historical frequency.

As mentioned above, the main conclusion of existing studies is that the production risk positively affects the amount of agricultural chemicals used. However, the influence of production risk on the dosage of alternatives to agricultural chemicals is uncertain. On the one hand, alternatives can be regarded as "new technologies", and their effect is more uncertain than agricultural chemicals. If farmers use alternatives to replace agricultural chemicals, production risk will inhibit the adoption of alternatives. On the other hand, alternatives have the function of controlling damage. If using alternatives reduces the production risk

further, then the higher the production risk, the higher the possibility of using alternatives. In addition, the motivation of farmers to use alternatives depends on the level of production risk. Predictably, the higher the production risk, the more likely farmers are to use alternatives to control the production risk. In general, production risk may positively impact the adoption of alternatives and is not conducive to reducing antibiotics. The empirical analysis is followed to verify this inference.

3. Research Methodology

3.1. Econometric model

At the initial stage of alternatives entering the market, farmers' decision to adopt alternatives depends on production risks and individual production characteristics. The estimation model is shown in Eq. (1).

$$Substitute_0 = \alpha + \alpha_1 Death + \alpha_2 X + \varepsilon \quad (1)$$

$Substitute_0$ is a dummy. If farmers adopted alternatives in the early stage of alternatives entering the market ($t = 0$), $Substitute_0$ equals 1 and otherwise 0.

Production risk $Death$ is represented by the average mortality rate lagged for at least t batches ($Death_{-t, past, m}$), the standard deviation of mortality rate lagged for at least t batches ($Death_{-t, past, sd}$), the average mortality rate lagged for t to $(t+1)$ batches ($Death_{-t \sim -(t+1), m}$), the standard deviation of mortality rate lagged for t to $(t+1)$ batches ($Death_{-t \sim -(t+1), sd}$), the mortality rate lagged for t batches ($Death_{-t}$), and the difference between the mortality rate lagged for t and $(t+1)$ batches. Individual production characteristics X include the cost of antibiotics, vaccines, disinfectants, and nutrition drugs, breeding density and number of chicken houses in the last batch. In addition, in order to control the influence of unobservable factors, X also includes a series of dummy variables on the breed of chicks, the month when the breeding circle starts, and the technician in charge of the farmer. ε_i is the random error term.

This study also focuses on the effect of alternatives adoption and the impact of production risk on the effect. The effect of alternatives adoption refers to the change of the amount of antibiotics used and the mortality rate in the initial stage of alternatives entering the market. The model is as follows.

$$\Delta Anti_{0-(-t)} = \beta + \beta_1 Substitute_0 + \beta_2 Z + \mu_1 \quad (2a)$$

$$\Delta Death_{0-(-t)} = \gamma + \gamma_1 Substitute_0 + \gamma_2 Z + \mu_2 \quad (2b)$$

$\Delta Anti_{0-(-t)}$ denotes the change of antibiotics usage, $\Delta Death_{0-(-t)}$ denotes the change of mortality rate, Z represents the individual production characteristics that influence antibiotic usage and mortality rate, including age, breeding experience, costs of vaccines, disinfectants and nutrition drugs, breeding density and number of chicken houses. On the basis of Equations (2a) and (2b), adding the interaction term of whether adopting alternatives and production risk ($Substitute_0 * Death$), we will obtain Equations (3a) and (3b) below.

$$\Delta Anti_{0-(-t)} = \chi + \chi_1 Substitute_0 + \chi_2 Substitute_0 * Death + \chi_3 Z + \mu_3 \quad (3a)$$

$$\Delta Death_{0-(-t)} = \delta + \delta_1 Substitute_0 + \delta_2 Substitute_0 * Death + \delta_3 Z + \mu_4 \quad (3b)$$

Suppose the coefficient of the interaction term in Eq. (3a) is positive and the coefficient in Eq. (3b) is negative. In that case, it indicates that farmers regard the alternatives as damage control inputs. High production risk encourages farmers to increase antibiotics usage while using alternatives to realize the purpose of controlling production risk.

3.2. Data and variables

The data of farmers' inputs, outputs and characteristics come from a wholly-owned subsidiary of a listed company in the broiler industry. All the sampled farmers contract with the subsidiary. The data are represented in two aspects. First, due to environmental regulations and technological constraints, the threshold of the broiler industry has been gradually raised, small and medium-sized farmers have accelerated exit, and the scale and industrialization level has been continuously improved. Data show that between 2004 and 2017, the number of farms with an annual output of 2,000 to 10,000 broilers decreased by half, while the number of farms with an annual output of more than 50,000 broilers increased fourfold (MARAC, 2005–2018). At the same time, the number of leading enterprises gradually increased and their market share continues to improve. In 2019, the total number of broilers sold in China was 9.3 billion, among which, the total number of broilers sold by the five listed companies in the broiler industry reached 2.258 billion, accounting for a quarter of the national total. The sampled company in this study is one of the five listed companies with 22 wholly-owned subsidiaries, mainly located in Jiangsu, Anhui and other provinces. Second, the sampled subsidiary, located in Changzhou, Jiangsu Province, is one of the first enterprises in Jiangsu province to participate in the pilot work of antibiotics reduction, providing good experience materials and detailed data for this study.

The sampled company adopts the "company + farmer" mode to cooperate with farmers to raise chickens. The company provides farmers with baby chick, feed, medicines, training and technical guidance and checks the quality and reclaims finished chickens. Farmers need to build sheds following the company's standards, pay security deposits in advance, and carry out breeding management according to the company's requirements. The company sets the prices of these materials and finished chickens, and farmers receive materials from the company on a credit basis. After the broilers are slaughtered, the company will settle the gross profit. In essence, the cooperation between the company and the farmers is a commissioned processing relationship. The company bears the market risk and part of the production risk, and the farmers obtain the average return promised by the company and bear part of the production risk. Farmers may incur losses if costs overrun or improper management happens. Farmers need to improve breeding performance through using a large number of antibiotics and working hard.

The company allocates a technician for about every 40 farmers. The technicians are responsible for providing technical guidance and services. They visit the farmers regularly (at least once a week) throughout the whole breeding process. For the use of preventive antibiotics, the company has a clear medication process and dosage instructions. The technician will regularly issue a prescription for preventive drugs, and the farmers will go to the company to get the medicine with the prescription. Farmers should use drugs as required by the company, but technicians will try to meet the demand of excessive drugs within a reasonable range. The implication of "within a reasonable range" is that farmers cannot increase the use of antibiotics without restriction because excessive use of antibiotics can lead to problems such as drug poisoning, slow growth, and reduced productivity. Concerning antibiotics for disease treatment, if farmers suspect that the broilers have disease symptoms, they can contact the technicians instantly for diagnosis and treatment. The contract points out that contracted farmers are not allowed to buy drugs privately, and the use of all kinds of illegal drugs and additives is strictly prohibited. The company mainly relies on drug residue testing to control farmers' antibiotics usage. Before each batch is sold, the company's testing department conducts spot checks. If the residue test is qualified, the farmer will be rewarded 0.2 yuan per broiler. If unqualified, farmers will lose rewards and face a fine of 0.3 yuan per broiler. The penalty accounts for about 10% of the gross profit got from the company.

In response to the government's call and to actively undertake the social responsibility of producers, the sampled subsidiary began to supply acidifier, an alternative to preventive antibiotics, to farmers in July 2018 after much consideration. Many natural experiments have shown that acidifiers can effectively prevent animal diseases and are an economical alternative to antibiotics (Thompson & Hinton, 1997; Abdel-Fattah et al., 2008). As with other production materials, farmers receive acidifiers from companies on credit. From July to November 2018, which is the initial stage of acidifier entering the market (farmers can obtain alternatives from the company), 51 farmers adopted alternatives under the promotion of technicians. In the meantime, a total of 380 farmers are in the breeding period. The company provided the production data of the 380 farmers in the past two years and in the initial stage. The data mainly included the number of chicks, the mortality rate, the cost of antibiotics, the cost of vaccines, the cost of disinfectants, the cost of nutrition drugs, etc. The company also provides individual characteristics such as age and years of broiler breeding.

The definition of variables and descriptive statistics are reported in Table 1. The average farmer is 45 years old and has four years of experience in poultry farming. Most farmers have two chicken houses, and the number of chicks per house is about 12,000. According to the length of the breeding period, broilers are mainly divided into fast, medium and slow breeds, whose average breeding period is 61 days, 80 days and 94 days, respectively. Under the condition of relatively stable production, farmers produce on average 3 batches of broilers a year. About 11% of the sample farmers (mainly new contractors) had produced only 1 to 2 batches of broilers in the past 2 years, 84% had produced 3 or more batches of broilers, and 58% had produced 6 or more batches of broilers. From the mortality rate lagged for one to six batches, it can be seen that the mortality rate will gradually decrease with the increase of breeding experience.

Table 1

Definition and descriptive statistics of variables

Name	Definition	Mean	S.D.
Dependent variables			
$Substitute_0$	Whether use alternatives in the initial stage (yes = 1; no = 0)	0.134	0.341
$\Delta Anti_{0-(-3)}$	Difference between the cost of antibiotics in the initial stage and lagged 3 batches (yuan/head)	0.064	0.155
$\Delta Death_{0-(-3)}$	Difference between the mortality rate in the initial stage and lagged 3 batches (range from 0 to 1)	-0.032	0.090
Production risk			
$Death_{-1, past, m}$	Mean of the mortality rate lagged 1 and more batches	0.077	0.045
$Death_{-2, past, m}$	Mean of the mortality rate lagged 2 and more batches	0.079	0.047
$Death_{-3, past, m}$	Mean of the mortality rate lagged 3 and more batches	0.082	0.056
$Death_{-4, past, m}$	Mean of the mortality rate lagged 4 and more batches	0.084	0.064
$Death_{-5, past, m}$	Mean of the mortality rate lagged 5 and more batches	0.087	0.079
$Death_{-6, past, m}$	Mean of the mortality rate lagged 6 and more batches	0.092	0.109
$Death_{-1, past, sd}$	S.D. of the mortality rate lagged 1 and more batches	0.066	0.082
$Death_{-2, past, sd}$	S.D. of the mortality rate lagged 2 and more batches	0.069	0.088
$Death_{-3, past, sd}$	S.D. of the mortality rate lagged 3 and more batches	0.068	0.096
$Death_{-4, past, sd}$	S.D. of the mortality rate lagged 4 and more batches	0.068	0.107
$Death_{-5, past, sd}$	S.D. of the mortality rate lagged 5 and more batches	0.077	0.128
$Death_{-6, past, sd}$	S.D. of the mortality rate lagged 6 and more batches	0.082	0.144
$Death_{-1 \sim -2, m}$	Mean of the mortality rate lagged 1 and 2 batches	0.066	0.056
$Death_{-3 \sim -4, m}$	Mean of the mortality rate lagged 3 and 4 batches	0.079	0.061
$Death_{-5 \sim -6, m}$	Mean of the mortality rate lagged 5 and 6 batches	0.093	0.095
$Death_{-1 \sim -2, sd}$	S.D. of the mortality rate lagged 1 and 2 batches	0.036	0.062
$Death_{-3 \sim -4, sd}$	S.D. of the mortality rate lagged 3 and 4 batches	0.045	0.073
$Death_{-5 \sim -6, sd}$	S.D. of the mortality rate lagged 5 and 6 batches	0.066	0.129

Notes: the subscript - 1 denotes lagged for 1 batch.

Name	Definition	Mean	S.D.
$Death_{-1}$	Mortality rate lagged 1 batch	0.062	0.070
$Death_{-2}$	Mortality rate lagged 2 batches	0.071	0.080
$Death_{-3}$	Mortality rate lagged 3 batches	0.079	0.085
$Death_{-4}$	Mortality rate lagged 4 batches	0.079	0.084
$Death_{-5}$	Mortality rate lagged 5 batches	0.082	0.106
$Death_{-6}$	Mortality rate lagged 6 batches	0.101	0.163
$Death_{-3} - Death_{-4}$	Difference of mortality rate between lagged 3 and 4 batches	0.001	0.121
$Death_{-3} - Death_{-4, past, m}$	Difference of mortality rate between lagged 3 and at least 4 batches	-0.004	0.106
$Death_{-3} \cap Death_{-4}$	= 1 if $(Death_{-3} - Death_{-4}) > 0$, otherwise 0	0.498	0.501
$Death_{-3} \cap Death_{-4, past, m}$	= 1 if $(Death_{-3} - Death_{-4, past, m}) > 0$, otherwise 0	0.405	0.492
$Death_{-3} \cap Death_{-4, past, m} \cap S$	= 1 if $(Death_{-3} - Death_{-4, past, m} \cap Death_{-4, past, sd}) > 0$, otherwise 0	0.257	0.438
$Death_{-3} \cap Death_{-4, past, m} \cap S$	= 1 if $(Death_{-3} - Death_{-4, past, m} \cap Death_{-4, past, sd}) \geq 0$, otherwise 0	0.186	0.390
Control variables			
<i>Age</i>	Age of the household head (in years) in the initial stage	44.966	7.689
<i>Experience</i>	Years on experience in broiler farming in the initial stage	4.103	3.555
$Anti_{-1}$	Cost of antibiotics (yuan/head)	0.461	0.153
$Vaccine_{-1}$	Cost of vaccines (yuan/head)	0.135	0.033
$Disinfectant_{-1}$	Cost of disinfectants (yuan/ head)	0.022	0.020
$Nutrition_{-1}$	Cost of nutrition drugs (yuan/ head)	0.032	0.025
$Density_{-1}$	Breeding density = N. of chicks/area of poultry houses (head/m ²)	14.491	5.358
$House_{-1}$	Number of poultry houses	2.557	0.814
Notes: the subscript - 1 denotes lagged for 1 batch.			

4. Empirical Results

4.1. Production risk and the early adoption of the alternative

Given the prerequisite controlling the production characteristics in the last batch, using the Probit model, this study investigates the impact of production risk on adopting alternatives in the initial stage of alternatives entering the market. First of all, the average mortality rate and the variance of mortality rate lagged at least t batches are used to represent the production risk. The results (Table 2 and Table 3) show that the mean mortality rate lagged at least 2 and 3 batches had a significant positive impact on adopting alternatives. The former is significant at the 10% level and the latter at the 5% level. On average, the mean mortality rate lagged three batches increased by 0.01, and the likelihood of farmers using alternatives in the initial stage would increase by 0.729%. The coefficients of the mean mortality rate lagged at least 4 and more batches are not significant, suggesting that more recent information are more important to farmers (Barham et al., 2015).

In contrast, the effect of the standard deviation of the historical mortality rate was not significant. Farmers are more sensitive to the average level of historical mortality rate. This finding is inconsistent with the literature that emphasizes the importance of changes in mean output (Chavas et al., 2019).

Further, the mean and standard deviation of the mortality rate lagged t to $(t + 1)$ batches were used to represent the production risk (Table 4). The results showed that the mean and standard deviation of the mortality rate lagged 3 to 4 batches had a significant positive impact on adopting alternatives. On average, the mean mortality rate lagged 3 to 4 batches increased by 0.01, and the possibility of adopting alternatives in the early stage increased by 0.626%. An increase in the standard deviation of 0.01 increased the likelihood of farmers adopting alternatives by 0.590%.

Next, the mortality rate lagged t batches was used to represent production risk to determine the effect of the mortality rate lagged in each batch. As shown in Table 5, only the mortality rate lagged 3 batches had a significant positive impact on adopting alternatives. On average, the mortality rate lagged 3 batches increased by 0.01, the likelihood of farmers adopting alternatives increased by 0.670%. The insignificant effect of the mortality rate lagged 1 or 2 batches may be due to the low comparability of the environment lagged 1 and 2 batches with the initial stage. Farmers produce an average of 3 batches of broilers each year, and the production risk of broiler breeding in different seasons is obviously different. The external natural environment lagged 3 batches is basically the same as that of the initial stage. This reflects farmers' rationality on production decisions.

Table 2

The impact of production risk ($Death_{-t, past, m}$) on the early adoption of alternatives

	Substitute ₀					
	(1)	(2)	(3)	(4)	(5)	(6)
<i>Death</i> _{1, past, m}	0.735 (0.459)					
<i>Death</i> _{2, past, m}		0.771* (0.406)				
<i>Death</i> _{3, past, m}			0.729** (0.351)			
<i>Death</i> _{4, past, m}				0.071 (0.345)		
<i>Death</i> _{5, past, m}					0.063 (0.296)	
<i>Death</i> _{6, past, m}						0.082 (0.217)
<i>Age</i>	0.001 (0.003)	0.001 (0.003)	0.003 (0.003)	0.003 (0.003)	0.001 (0.003)	0.001 (0.004)
<i>Experience</i>	-0.013* (0.007)	-0.014* (0.007)	-0.016** (0.007)	-0.017** (0.007)	-0.017** (0.008)	-0.023*** (0.008)
<i>Anti</i> ₁	-0.113 (0.163)	-0.114 (0.163)	-0.162 (0.170)	-0.254 (0.182)	-0.398* (0.208)	-0.368 (0.228)
<i>Vaccine</i> ₁	0.389 (0.836)	0.421 (0.833)	-0.114 (0.891)	-0.746 (0.945)	-0.366 (1.035)	-1.240 (1.391)
<i>Disinfectant</i> ₁	-0.967 (1.353)	-0.867 (1.347)	-0.987 (1.401)	-0.689 (1.475)	0.436 (1.633)	0.076 (1.783)
<i>Nutrition</i> ₁	0.940 (0.988)	0.904 (0.990)	0.372 (1.092)	-0.041 (1.196)	-0.418 (1.398)	-0.369 (1.555)
<i>Density</i> ₁	0.003 (0.004)	0.003 (0.004)	0.003 (0.004)	0.004 (0.005)	0.005 (0.005)	0.007 (0.005)
<i>House</i> ₁	-0.040 (0.030)	-0.040 (0.030)	-0.035 (0.031)	-0.038 (0.033)	-0.022 (0.034)	-0.036 (0.037)
<i>Breed, month, and technician</i>	Yes	Yes	Yes	Yes	Yes	Yes
Observations	281	281	260	246	205	179

Note: *Asterisks denote significance at the 10% (*), 5% (**), and 1% (***) levels. $\text{Death}_{t, \text{past}, m}$ represents the mean of mortality rate lagged at least t batches.

Table 3

The impact of production risk ($\text{Death}_{t, \text{past}, sd}$) on the early adoption of alternatives

	Substitute ₀					
	(1)	(2)	(3)	(4)	(5)	(6)
<i>Death</i> _{-1, past, sd}	0.382					
	(0.246)					
<i>Death</i> _{-2, past, sd}		0.345				
		(0.230)				
<i>Death</i> _{-3, past, sd}			0.300			
			(0.214)			
<i>Death</i> _{-4, past, sd}				0.039		
				(0.224)		
<i>Death</i> _{-5, past, sd}					0.020	
					(0.212)	
<i>Death</i> _{-6, past, sd}						0.268
						(0.225)
<i>Control variables</i>	Yes	Yes	Yes	Yes	Yes	Yes
Observations	281	260	246	205	179	136

Note: Asterisks denote significance at the 10% (*), 5% (**), and 1% (***) levels. Control variables include age, experience, the cost of antibiotics, vaccines, disinfectants, and nutrition drugs, breeding density, and number of poultry houses in the last batch. In the following tables, *Control variables* have the same meaning. Compared with Table 2, the coefficients of the control variables were almost unchanged, and the results were very robust. *Death*_{-t, past, sd} represents the standard deviation of mortality rate lagged at least *t* batches.

Table 4

The impact of production risk (*Death*_{-t~-(t+1), m} and *Death*_{-t~-(t+1), sd}) on the early adoption of alternatives

	Substitute ₀					
	(1)	(2)	(3)	(4)	(5)	(6)
<i>Death</i> _{-1~-2, m}	-0.283					
	(0.478)					
<i>Death</i> _{-3~-4, m}		0.626**				
		(0.278)				
<i>Death</i> _{-5~-6, m}			0.004			
			(0.263)			
<i>Death</i> _{-1~-2, sd}				-0.325		
				(0.472)		
<i>Death</i> _{-3~-4, sd}					0.590***	
					(0.225)	
<i>Death</i> _{-5~-6, sd}						-0.002
						(0.189)
<i>Control variables</i>	Yes	Yes	Yes	Yes	Yes	Yes
Observations	281	246	181	281	246	179

Note: Asterisks denote significance at the 10% (*), 5% (**), and 1% (***) levels. *Death*_{-t~-(t+1), m} represents the mean of mortality rate lagged *t* to (*t*+1) batches, and *Death*_{-t~-(t+1), sd} represents the standard deviation of mortality rate lagged *t* to (*t*+1) batches.

Table 5

The impact of production risk (*Death*_{-t}) on the early adoption of alternatives

	Substitute ₀					
	(1)	(2)	(3)	(4)	(5)	(6)
<i>Death</i> ₁	-0.291					
	(0.470)					
<i>Death</i> ₂		-0.103				
		(0.295)				
<i>Death</i> ₃			0.670***			
			(0.221)			
<i>Death</i> ₄				0.038		
				(0.218)		
<i>Death</i> ₅					-0.073	
					(0.260)	
<i>Death</i> ₆						0.034
						(0.142)
<i>Control variables</i>	Yes	Yes	Yes	Yes	Yes	Yes
Observations	281	281	260	246	205	179

Note: *Asterisks denote significance at the 10% (*), 5% (**), and 1% (***) levels. $Death_t$ represents the mortality rate lagged t batches.

Given the significant impact of the mortality rate lagged 3 batches on the adoption of alternatives, the relative values of it are used to represent production risk, including the difference between the mortality rate lagged 3 and 4 batches. The difference between the mortality rate lagged 3 and at least 4 batches, whether the mortality rate lagged 3 batches is larger than the mortality rate lagged 4 batches, whether the mortality rate lagged 3 batches is larger than the average mortality rate lagged at least 4 batches, and whether the mortality rate lagged 3 batches is outside one standard deviation of the average mortality rate lagged at least 4 batches. The results (Table 6) show that the greater the increment in the mortality rate lagged 3 batches, the higher the likelihood of farmers adopting alternatives in the early stage. However, there was no significant effect on whether the mortality rate lagged 3 batches was higher than the historical mortality rate, or whether it was outside one standard deviation of the average historical mortality rate. Therefore, farmers are more sensitive to the value of mortality rate in the past, and the conclusion is consistent with the previous ones.

Table 6

The impact of production risk (relative $Death_3$) on the early adoption of alternatives

	Substitute ₀					
	(1)	(2)	(3)	(4)	(5)	6
<i>Death₃Death₄</i>	0.372** (0.181)					
<i>Death₃Death_{4, past, m}</i>		0.484** (0.193)				
<i>Death₃Death₄</i>			0.028 (0.046)			
<i>Death₃Death_{4, past, m}</i>				0.042 (0.049)		
<i>Death₃Death_{4, past, m}S</i>					-0.001 (0.064)	
<i>Death₃Death_{4, past, m}S</i>						0.024 (0.068)
<i>Control variables</i>	Yes	Yes	Yes	Yes	Yes	Yes
Observations	246	246	246	246	205	205

Note: Asterisks denote significance at the 10% (*), 5% (**), and 1% (***) levels. Variable *Death₃Death₄* equals 1 if (*Death₃Death₄*)>0 and otherwise 0. Variable *Death₃Death_{4, past, m}* equals 1 if (*Death₃Death_{4, past, m}*)>0 and otherwise 0. Variable *Death₃Death_{4, past, m}S* equals 1 if (*Death₃Death_{4, past, m}Death_{4, past, sd}*)>0 and otherwise 0. Variable *Death₃Death_{4, past, m}S* equals 1 if (*Death₃Death_{4, past, m}Death_{4, past, sd}*)=0 and otherwise 0.

To test the robustness of the impact of production risk on the early adoption of alternatives, this study replaced the Probit model with the OLS model. The significance and direction of the coefficients of each variable did not change, and the results were robust. Due to space limitations, the OLS model results are shown in the appendix.

The above results indicate that the higher the production risk, the higher the likelihood of farmers to adopt alternatives at the initial stage of alternatives entering the market. However, compared with antibiotics, substitutes are new technologies, and the uncertainty of disease prevention effect is higher than that of antibiotics. So the production risk should be unfavorable to the adoption of alternatives. One exception is when farmers take advantage of the disease prevention benefits of alternatives and use them without reducing the amount of antibiotics to further reduce production risks. This raises a new question: how will farmers' use alternatives affect their antibiotics use and mortality rate? Which role does production risk play? These questions will be answered one by one.

4.2. The effects of the early adoption of the alternative

The first two columns of Table 7 report the impact of adopting alternatives on antibiotics usage and the mortality rate at the initial stage of alternatives entering the market. To improve the reliability of estimation results based on cross-sectional data, the difference of the cost of antibiotics (and mortality rate) between the initial and lagged three batches was used as the dependent variables. The results show that the use of alternatives can significantly reduce antibiotics usage and mortality rate. Acidifiers do not treat diseases but prevent intestinal diseases and substitute for antibiotics in prevention. Through in-depth interviews with technicians and farmers, it is learned that some farmers do not reduce the dosage of preventive antibiotics when using acidifiers. And such use will reduce the incidence of disease, the use

of therapeutic antibiotics and the death rate. Just and Pope (1979) found that fertilizer use tends to increase production risk. Chavas et al. (2019) also verify that variable inputs contribute to increasing risk. However, this study argues that alternatives to agricultural chemicals contribute to reducing risk.

In this process, production risk plays an important role. As shown in columns 3 and 4, the interaction term between whether using alternatives and the mortality rate lagged three batches was added to the basic model. The results showed that the higher the mortality rate lagged three batches under the use of alternatives, the higher the antibiotics usage was, and the lower the mortality rate was. This proves that production risk has an important regulating effect on the effect of alternatives adoption, and higher production risk will promote farmers to use alternatives without reducing the amount of antibiotics to further reduce production risk.

Table 7
The effects of alternatives use

	$\Delta\text{Anti}_{0-(-3)}$	$\Delta\text{Death}_{0-(-3)}$	$\Delta\text{Anti}_{0-(-3)}$	$\Delta\text{Death}_{0-(-3)}$
	(1)	(2)	(3)	(4)
Substitute ₀	-0.095*** (0.027)	-0.043*** (0.016)	-0.133*** (0.031)	0.070*** (0.014)
Death ₋₃			0.338** (0.145)	-0.991*** (0.064)
<i>Control variables</i>	Yes	Yes	Yes	Yes
Constant	0.086 (0.100)	0.020 (0.059)	0.092 (0.099)	0.002 (0.043)
Observations	317	317	317	317
R-squared	0.181	0.139	0.196	0.534

Note: *Asterisks denote significance at the 10% (*), 5% (**), and 1% (***) levels. $\Delta\text{Anti}_{0-(-3)}$ is the difference between the cost of antibiotics in the initial stage and lagged 3 batches, and $\Delta\text{Death}_{0-(-3)}$ is difference between the mortality rate in the initial stage and lagged 3 batches. *Control variables include age, experience, the cost of vaccines, disinfectants, and nutrition drugs, breeding density, and number of poultry houses in the initial stage.

5. Conclusion

Based on contract farmers' breeding performance data, this study empirically analyzes the impact of production risk on the adoption and effect of alternatives at the initial stage of alternatives entering the market. The production risk was described from multiple dimensions, such as the average level of historical mortality rate and the variance of historical mortality rate. Meanwhile, Probit and OLS models were used to verify the robustness of the results, and the following conclusions were obtained. First, the average historical mortality rate explains more about farmers' behavior than the fluctuation of historical mortality rate. Second, the mortality rate lagged three batches has a significant positive impact on the adoption of alternatives by farmers. In comparison, the impact of the mortality rate lagged one or two batches is not significant, fully reflecting the rationality of farmers' decision-making. Third, the production risk has a significant impact on the effect of alternatives. When using alternatives, the mortality rate lagged three batches is higher; the higher the dosage of antibiotics used, the lower the mortality rate,

suggesting that higher production risk would lead to farmers using alternatives to further reduce the production risk rather than to reduce antibiotics use.

Based on the findings above, the core standpoint of this paper is that the adoption of alternatives cannot be directly linked to the reduction of agricultural chemicals. The reduction effect of alternatives varies from farmer to farmer. Only those farmers with low production risk in the past experience will try to reduce the amount of agricultural chemicals by using alternatives. Otherwise, alternatives may be used as supplements to agricultural chemicals. In this case, although farmers can benefit from the use of alternatives (production risk reduction), it is against the original intention of reducing agricultural chemicals. To realize the reduction effect of alternative to agricultural chemical, the prerequisite is to improve farmers' production risk management ability. Leading enterprises and local governments should strengthen training related to production risk management, help farmers reduce production risks through scientific breeding and investment in modern production facilities, and then promote agricultural chemicals to farmers when the time is ripe.

Declarations

Ethical Approval Not applicable.

Consent to participate The authors declare that they agree to publish this paper in Environmental Science and Pollution Research.

Consent to publish The authors declare that they agree with the publication of this paper in this journal.

Authors contributions Lingzhi Li: Data collection; Analysis; original draft

Li Zhou: Conceptualization; supervision; review and editing

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Availability of data and materials The authors declare that the data are not available and can be presented upon the requested of the readers.

References

1. Abdel-Fattah, S. A., El-Sanhoury, M. H., El-Mednay, N. M., and Abdel-Azeem, F. 2008. Thyroid Activity, Some Blood Constituents, Organs Morphology and Performance of Broiler Chicks Fed Supplemental Organic Acids. *International Journal of Poultry Science* 7, 215-222.

2. Abdollahzadeh, G., Sharifzadeh, M. S., and Damalas, C. A. 2015. Perceptions of the Beneficial and Harmful Effects of Pesticides among Iranian Rice Farmers Influence the Adoption of Biological Control. *Crop Protection* 75, 124-131.
3. Anderson, J. R. and Griffiths, W. E. 1982. Production risk and efficient allocation of resources. *Australian Journal of Agricultural Economics* 26 (3), 226-232.
4. Barham, B. L., Chavas, J. P., Fitz, D., Ríos-Salas, V., and Schechter, L. 2015. Risk, Learning, and Technology Adoption. *Agricultural Economics* 46, 11-24.
5. Burbee, C. R., and Green, B., and Matsumoto, M. 1985. Antibiotics in Animal Feeds: Risks and Costs. *American Journal of Agricultural Economics* 67(5), 966-970.
6. Chavas, J., Cooper, J., and Wallander S. 2019. The Impact of Input and Output Decisions on Agricultural Production Risk. *Journal of Agricultural and Resource Economics* 44(3), 513–535.
7. Gao, Y., Zhang, X., Lu, J., Wu, L., and Yin, S. 2017. Adoption Behavior of Green Control Techniques by Family Farms in China: Evidence from 676 Family Farms in Huang-Huai-Hai Plain. *Crop Protection* 99(9), 76-84.
8. Gong, Y., Baylis, K., Kozak, R., and Bull, G. 2016. Farmers' Risk Preferences and Pesticide Use Decisions: Evidence from Field Experiments in China. *Agricultural Economics* 47(4), 411-421.
9. Hardaker, B. 2016. Comment 2 on 'Risk and uncertainty' by Quiggin and Anderson. *Australian Journal of Agricultural and Resource Economics* 60, 552-553.
10. Just, R. E., and Pope, R. D. 1979. Production Function Estimation and Related Risk Considerations. *American Journal of Agricultural Economics* 61, 276–284.
11. Kemper, N. 2008. Veterinary Antibiotics in the Aquatic and Terrestrial Environment. *Ecological indicators* 8, 1-13.
12. Khan, M., and Damalas, C. A. 2015. Farmers' Knowledge about Common Pests and Pesticide Safety in Conventional Cotton Production in Pakistan. *Crop Protection* 77(11), 45-51.
13. Kingwell, R., and Farre, I. 2009. Climate change impacts on investment in crop sowing machinery. *Australian Journal of Agricultural and Resource Economics* 53(2), 265-284.
14. Komareka, A.M., De Pintoa, A., and Smith, V. H. 2020. A Review of Types of Risks in Agriculture: What We Know and What We Need to Know. *Agricultural Systems* 178.
15. Laxminarayan R. 2001. Economics of Antibiotic Resistance: A Theory of Optimal Use. *Journal of Environmental Economics and Management* 42(2), 183-206.
16. Lichtenberg, E., and Zilberman, D. 1986. The econometrics of damage control: why specification matters. *American Journal of Agricultural Economics* 68(2), 261-273.
17. Liu, E. M., and Huang, J. 2013. Risk Preferences and Pesticide Use by Cotton Farmers in China. *Journal of Development Economics* 103(4), 202-215.
18. MARAC (Ministry of Agriculture and Rural Affairs of China). 2005-2018. *China Animal Husbandry and Veterinary Yearbook*. [2021-07-22]. <https://navi.cnki.net/knavi/YearbookDetail?pcode=CYFD&pykm=YZGXM> (in Chinese)

19. MARAC (Ministry of Agriculture and Rural Affairs of China). 2019. *Official Veterinary Bulletin*. [2021-07-10]. <http://www.moa.gov.cn/gk/sygb/201911/P020191108590803635472.pdf> (in Chinese)
20. Moser, R., Pertot, I., Elad, Y., and Raffaelli, R. 2008. Farmers' Attitudes Toward the Use of Biocontrol Agents in IPM Strawberry Production in Three Countries. *Biological Control* 47, 125-132.
21. Riwthong, S., Schreinemachers, P., Grovermann, C., and Berger, T. 2017. Agricultural Commercialization: Risk Perceptions, Risk management and the role of Pesticides in Thailand. *Kasetsart Journal of Social Sciences* 38, 264-272.
22. Sarmah, A. K., Meyer, M. T., and Boxall, A. B. A. 2006. A Global Perspective on the Use, Sales, Exposure Pathways, Occurrence, Fate and Effects of Veterinary Antibiotics (VAs) in the Environment. *Chemosphere* 65, 725-759.
23. Thompson, J.L., and Hinton, M. 1997. Antibacterial activity of formic and propionic acids in the diet of hens on Salmonella in the crop. *British Poultry Science* 38, 59-65.
24. Yee, J., and Ferguson, W. 1996. Sample selection model assessing professional scouting programs and pesticide use in cotton production. *Agribusiness* 12, 291-300.
25. Zhang, P., Shen, Z., Zhang, C., Song, L., Wang, B., Shang, J., Yue, X., Qu, Z., Li, X., Wu, L., Zheng, Y., Aditya, A., Wang, Y., Xu, S., and Wu, C. 2017. Surveillance of Antimicrobial Resistance among *Escherichia coli* from Chicken and Swine, China, 2008-2015. *Veterinary Microbiology* 203, 49-55.
26. Zhou, L., Zhang, F., Zhou, S., and Turvey, C. G. 2020. The Peer Effect of Training on Farmers' Pesticides Application: A Spatial Econometric Approach. *China Agricultural Economic Review* 12, 481-505.

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