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The impact of epidemic experiences on biosecurity behavior of pig farmers: an analysis based on protection motivation theory

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ABSTRACT

Farm biosecurity is considered an important component of "One Health". Biosecurity measures are crucial for preventing and controlling outbreaks and spread of diseases on farms. Protection motivation theory (PMT) links perception of risk and coping ability with taking preventive actions. Based on field survey data of pig farmers, this study utilizes OLS and mediating effect model to explore the impact and mechanism of epidemic experiences on farmers' implementation of biosecurity measures. The research findings are as follows: first, epidemic experiences significantly promote farmers' implementation of biosecurity measures. The conclusion remains robust after addressing potential endogeneity issues. Second, epidemic experiences, through accumulated experience, further encourage farmers to implement biosecurity measures. Third, the impact of epidemic experiences on farmers' biosecurity behavior shows heterogeneity in farm size. Compared to small-scale farmers, epidemic experiences have a greater promoting effect on biosecurity behavior of professional farmers. Therefore, emphasizing farmers' epidemic experiences, enhancing biosecurity training, and increasing farmers' awareness are of significant importance in promoting farmers' implementation of biosecurity measures.

1. Introduction

As the world's largest producer and consumer of pork, China's pig industry is crucial to agricultural economy and farmers' income [1]. Data shows that in 2022, China's pork production reached 55.41 million tons, accounting for approximately 44.5% of the world's total production, and pork consumption accounts for about half of the world's total consumption [2]. The pig industry has made significant contributions to the agricultural GDP. However, in recent years, the pig industry has frequently been threatened by infectious diseases, which may lead to significant economic losses and public health issues [3].

Biosecurity, defined as a set of management practices or measures to prevent the risk of disease pathogens being introduced and spread within and between farms [4–6]. It is considered the first line of defense against highly pathogenic influenza [7]. Implementing biosecurity measures helps reduce the risk of introducing pathogens to farms [8], thereby lowering the incidence and spread of infectious diseases on farms. Furthermore, biosecurity measures play a positive role in reducing economic losses [9], decreasing antibiotic usage [10], and improving animal health and welfare [11,12]. Overall, implementing biosecurity measures may still be the only realistic method for preventing and controlling diseases in the near future [13]. Although biosecurity measures play an important role in preventing infectious diseases, the implementation rate of biosecurity measures remains at a low level. A study on Chinese pig farms revealed that the biosecurity level of most farms is not ideal, with the biosecurity situation at some farms being worrying [14].

Scholars have conducted numerous studies on farmers' biosecurity behavior, mainly focusing on the following aspects: (1) Farmers. Farmers' personality traits, work experience, education, knowledge and attitudes are often emphasized as the main influencing factors for implementing biosecurity measures [15–20]. (2) Biosecurity measures (BSM). The implementation costs of BSM [21], feasibility [22,23], awareness of the benefits or effectiveness of BSM [24], and obtaining information on BSM [25] play a role in the implementation of biosecurity measures. (3) Other factors. Veterinarians [4,26,27], training [28], contract farming [29], farm business type [30], community participation [31], and other factors have a significant impact on farmers' implementation of biosecurity measures.

However, what is currently unclear is how epidemic experiences affect farmers' biosecurity behavior. In other words, biosecurity behavior of farmers affected by animal infectious diseases has not been

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comprehensively described. With the increasing number and types of global infectious diseases, the impact of previous infectious diseases on future behavior is becoming increasingly important. Chinese farmers have been affected by many animal diseases, such as FMD in cattle, pigs and sheep after 1999, HPAI since 2004, *streptococcus suis* in Sichuan in 2005, and a swine PRRS-like disease in 2006, African Swine Fever (ASF) in 2018 [1]. On one hand, these diseases have brought a series of profound impacts on farmers, consumers, and meat markets. For example, these diseases can lead to a decrease in Gross Domestic Product (GDP) and economic losses [32], imbalance in the supply and demand of meat markets [33], and a significant increase in pork price [34]. They may also result in human epidemics or pandemics [3]. In addition, some farmers may exit pig production or reduce their production scale [35]. On the other hand, the experiences of these epidemics may have significant impacts on farmers' subsequent psychological traits, cognitive structures, knowledge, and skills, thereby influencing their later behavioral decisions [36,37]. Protection motivation theory (PMT) links individuals' perception of risk and coping ability with the adoption of preventive behavior [38], used to describe and predict the adoption of preventive behavior based on risk perception, and specifically attributes decision-making to threat appraisal and coping appraisal.

In view of this, this study analyzes the impact and mechanism of epidemic experiences on biosecurity behavior of pig farmers by constructing a PMT framework. In addition, the study explores the heterogeneity of this impact. The study attempts to answer the following questions: (1) What is the impact of epidemic experiences on the implementation of biosecurity measures by pig farmers? (2) What is the mechanism by which epidemic experiences affect farmers' biosecurity behavior? (3) Is there heterogeneity in the impact of epidemic experiences on farmers' biosecurity behavior?

Compared with previous studies, this study may have three potential marginal contributions. Firstly, from the perspective of previous epidemics, the study explores the impact of epidemic experiences on biosecurity behavior of pig farmers, providing a new perspective on biosecurity. As pointed out in a study by Islam et al. [39], a limitation is the lack of investigation into diseases encountered in poultry farms in the past. Our study overcomes this limitation by recording farmers' experiences of infection with infectious diseases on their farms. Secondly, a PMT framework was constructed to analyze the underlying influence mechanism of epidemic experiences on farmers' biosecurity behavior. Several studies utilizing PMT to explore farmers' implementation of biosecurity measures focus only on the theoretical level [40,41]. Our study not only conducts theoretical analysis but also empirically tests the influence mechanism using mediation effect model. Thirdly, this study fully considers heterogeneity. From the perspective of farming scale, it explores the differential impact of epidemic experiences on biosecurity behavior of farmers of different scales.

The rest of this study is structured as follows: Section 2 elaborates on the theoretical framework of the relationship between epidemic experiences and biosecurity behavior and proposes research hypotheses. Section 3 introduces data, variables, and methods of the study. Section 4 presents the empirical results. Section 5 discusses the main research findings. Section 6 summarizes the main conclusions of this study and provides policy implications.

2. Theoretical framework and research hypotheses

Protection motivation theory (PMT) is a cognitive theory that links individuals' perception of risk and coping ability with preventive behavior [38]. PMT was initially used to study issues related to health behavior [42,43]. However, it was soon expanded to agricultural field and has been widely applied to pro-environmental behavior [44–46], such as application of pesticides and fertilizers, practice of classifying wastes, and integrated pest management practices, as well as climate change adaptation behavior [47–50], such as responses to drought, rising temperatures, and changes in precipitation. The theory has also been applied in the field of biosecurity among farmers [40,41,51].

The two key elements of PMT are threat appraisal and coping appraisal [46,50]. Threat appraisal includes perceived severity (individual's assessment of the seriousness of the risk) and perceived susceptibility (individual's perception of the likelihood of infection). Coping appraisal refers to individual's perceived ability to cope with the identified threat, including self-efficacy (individual's confidence and ability to engage in the behavior), response efficacy (individual's perception of the effectiveness of preventive behavior) and response cost (individual's perception of the cost of preventive behavior). PMT posits that if an individual actively perceives each element in these structures, the individual will engage in preventive behavior. In simple terms, when an individual is aware of the seriousness of the health threat (severity), perceives themselves as susceptible to the disease (susceptibility), believes in the benefits of preventive actions (response efficacy), has confidence and ability to take actions (self-efficacy), and considers the cost of taking measures to be reasonable (response cost), the individual's protection motivation is maximized, leading to protective behavior. Specifically for pig farmers, if farmers perceive the risk of infection in their farms as serious and likely, and believe that implementing biosecurity measures such as establishing segregation zones, disinfection, is achievable and effective, farmers will implement biosecurity measures to reduce the likelihood of their farms being affected by the disease.

On one hand, epidemic experiences can enhance farmers' threat appraisal. (1) Severity of threat: previous risk experiences have positively influenced farmers' perception of biosecurity threats [52]. Farmers who have experienced epidemics in the past are able to realize the serious consequences of the disease firsthand, such as reduced feed intake, decreased activity, and even unnatural deaths [53]. Compared to farmers who have not experienced an epidemic, they have a higher risk awareness, able to timely perceive potential risks and the severity of risks [54,55]. This perception of threat severity motivates farmers to generate preventive motives, prompting them to implement more biosecurity measures to reduce losses [56]. (2) Susceptibility of threat: epidemic experiences may influence farmers' perception of vulnerability to other biosecurity risks through various possible channels [57]. Farmers who have experienced past epidemics are aware that their own farms are also vulnerable to other disease risks. They perceive their farms as "disease-susceptible farms." This awareness of vulnerability to threat motivates them to enhance prevention awareness and take timely biosecurity management measures to reduce losses from other diseases.

On the other hand, epidemic experiences can improve farmers' coping appraisal. (1) Self-efficacy: farmers who have experienced epidemics have a better understanding of clinical symptoms and epidemiological characteristics of diseases. In addition, these farmers may receive detailed information about diseases from the government and veterinarians, such as the path and speed of pathogen transmission. The rich disease knowledge and information enhance farmers' confidence and ability to effectively cope with future biosecurity risks. Of course, the enhancement of self-efficacy motivates farmers to implement biosecurity measures to cope with other epidemics [51]. (2) Response efficacy: farmers' perception of the effectiveness of biosecurity measures is an important determining factor in implementing such measures [24,58]. Pig farmers who believe biosecurity measures are effective are more willing to invest time and money in taking biosecurity measures [40]. As they have actually implemented biosecurity measures on their farms, farmers who have experienced epidemics are aware of the importance of implementing specific biosecurity measures in preventing disease and improving productivity. This understanding of the effectiveness of biosecurity measures in turn encourages farmers to more actively implement biosecurity measures.

Therefore, compared to pig farmers who have not experienced epidemics, those who have can perceive the serious biosecurity threats on their farms (severity), consider their own farms as susceptible to diseases (susceptibility), recognize the benefits of biosecurity measures (response efficacy), and have confidence and ability to improve farm biosecurity (self-efficacy). The protective motivation of these farmers is maximized, prompting them to engage in protective behavior, namely, implementing biosecurity measures. In order to facilitate the subsequent examination of the influence mechanism of epidemic experiences on biosecurity behavior, this study collectively refers to severity of threat, susceptibility of threat, self-efficacy, and response efficacy as accumulated experience.

Based on the above analysis, this study proposes the following hypotheses:

H1. Epidemic experiences have a positive impact on pig farmers' biosecurity behavior.

H2. Epidemic experiences promote farmers' biosecurity behavior through accumulated experience.

To conclude, Fig. 1 illustrates the theoretical analysis above.

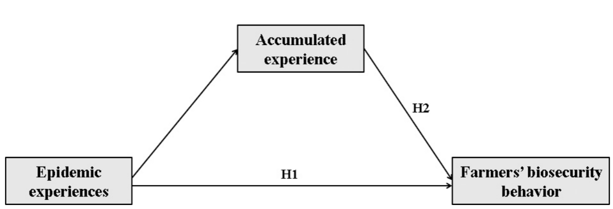

Fig. 1. Theoretical analytical framework.

3. Data, variables and methods

3.1. Data source

The data used in this study was collected from a questionnaire survey conducted by the research group from October to December 2019 in 10 counties in Sichuan, Henan, Shandong, Hunan, and Anhui provinces on pig farmers. The selection of sample areas was mainly based on two factors: firstly, these areas are the main pig production and breeding intensive areas in China. The output of live pigs, the annual inventory of live pigs, and pork production have ranked among the top for many years in these areas. They play an important role in stabilizing supply of pigs in China. Secondly, these areas are all to varying degrees affected by various animal diseases, which have brought changes to farmers' production behavior. Therefore, the above areas have a certain representativeness in studying the impact of epidemic experiences on biosecurity behavior of pig farmers.

The research team employed a combination of typical surveys, stratified sampling, and random sampling to select sample households. The survey targeted household heads or other family members involved in production and management decisions. The survey method involved "face-to face" interviews between interviewers and interviewees. The survey content mainly included the basic characteristics of the farmers and their families, pig farming status, epidemic experiences, implementation of biosecurity measures, and other aspects. After excluding invalid questionnaires with missing key information and logical inconsistencies, a total of 476 valid questionnaires were obtained.

3.2. Variable setting and descriptive statistical analysis

3.2.1. Dependent variable

Dependent variable is farmers' biosecurity behavior. Good biosecurity measures include segregation and sanitation [30]. In pig farms, "segregation" refers to creating and maintaining physical or virtual barriers to limit the potential opportunities for infected animals and contaminated materials to enter uninfected areas [9], thereby reducing introduction and spread of pathogens. "Sanitation" refers to cleaning and disinfecting pigpens, farmers, and equipment to significantly reduce disease transmission by lowering microbial levels in the environment to non-infectious levels. Therefore, this study combines the actual situation of pig production in China with the "Technical Guidelines for Disease Prevention and Control in Pig Farms" to assess farmers' biosecurity behavior based on the following questions: (1) Segregation: Is there a segregation zone constructed around your farm? This variable is binary, assigned a value of 1 if the farmer answers yes, otherwise 0. (2) Sanitation: Does your farm strictly enforce changing clothes when entering the production area? This variable is also binary, assigned a value of 1 if the farmer answers yes, otherwise 0. (3) Disinfection: How many times does your farm disinfect per year? This variable is continuous. To reduce the gap in the data, the disinfection variable is log-transformed. Finally, using the entropy method to weight each indicator, the biosecurity level of farms is calculated to represent farmers' biosecurity behavior.

In terms of biosecurity management on farms, only 21.4% of farmers have established quarantine zones on their farms. Less than half of farmers change clothes before entering their farms. The fact that so many farms lack quarantine zones and do not change clothes is startling. On average, farmers disinfect their facilities and equipment once every 10 days (Table 1).

3.2.2. Independent variable

The independent variable is epidemic experiences. It is a binary variable, with a value of 1 if the farmer has experienced an epidemic and 0 otherwise. The questionnaire item "Have you experienced pig epidemics (such as blue ear disease, swine fever, swine flu, or other pig diseases): Yes=1, No=0" is used to measure the variable.

Table 1
The definition, assignment and descriptive statistics of variables.

Variables	Definition, assignment	Mean	SD
Biosecurity behavior	Calculated using the entropy method, the value ranges from 0 to 1	0.313	0.339
Construct segregation zones	Yes = 1, No = 0	0.214	0.411
Change clothes	Yes = 1, No = 0	0.424	0.495
Disinfect	Total number of disinfection times per year (log-transformed)	3.570	2.252
Epidemic experiences	Yes = 1, No = 0	0.460	0.499
Characteristics of individuals and their families			
Age	Actual age of the household head (years)	55.494	9.877
Education	Years of education (years)	6.700	2.799
Health	Farmers' evaluation of their own health condition: Very poor = 1, Very good = 5	3.618	0.881
Household main decision-makers	Who makes the important decisions in your household: Male/Female = 0, Joint decision-making = 1	0.542	0.499
Characteristics of pig farming			
Number of farming labor	Number of laborers engaged in pig farming (people)	1.813	0.808
Farming experience	Number of years engaged in pig farming (years)	16.374	12.856
Farming scale	Total annual pig slaughter (log-transformed)	3.236	2.016
Percentage of income from farming	Percentage of income from pig farming out of total income (%)	0.568	0.385
Type of pigpen	Plastic greenhouse = 1, Simple brick and tile = 2, Modern pig farm = 3	2.168	0.391
Other external characteristics			
Veterinary service organizations	Are there veterinary service organizations in your village/town: Yes = 1, No = 0	0.813	0.390
Mediating variable			
Accumulated experience	Calculated	3.397	0.566

3.2.3. Mediating variable

The mediating variable is farmers' accumulated experience, measured by the following questions: (1) You perceive the production risk brought by African swine fever to be severe. This indicator represents severity of threat. (2) You frequently check your own farm for diseases. This indicator represents susceptibility of threat. (3) You are able to take timely prevention and control measures to cope with African swine fever. This indicator represents farmers' self-efficacy. (4) You consider it important to prevent and control the pig epidemic. This indicator represents farmers' response efficacy. All the above questions are measured using a Likert five-point scale, with standard answers ranging from 1 to 5, where 1 represents strongly disagree and 5 represents strongly agree. The entropy method is used to determine the weight of each question, and the weighted average of questions (1)–(4) is calculated to represent farmers' accumulated experience.

3.2.4. Control variables

Drawing on existing research [59,60], this study selects the following control variables: (1) Personal and household characteristics of the household head, including age, education level, health status, and household main decision-makers. (2) Characteristics of pig farming, including number of farming labor, farming experience, scale of farming, percentage of income from farming, and type of pigpen. (3) Other external characteristics, such as whether there are veterinary service organizations in the village or town.

Table 1 presents the definition, assignment, and descriptive statistical analysis for each variable.

3.3. Model specification

3.3.1. Baseline regression model

This study uses Ordinary Least Squares (OLS) to estimate the impact of epidemic experiences on biosecurity behavior. The specific form is:

$$Bsb = \alpha + \beta\, Experiences + \gamma\, Controls + \varepsilon \tag{1}$$

In the equation: *Bsb* represents farmers' biosecurity behavior, *Experiences* stand for epidemic experiences, *Controls* denote the control variables, including personal and family characteristics of farmers, farming characteristics, and other external features, α, β, γ are the coefficients to be estimated, and ε is the random error term.

3.3.2. Mediation effects model

This study adopts the stepwise regression method proposed by Baron and Kenny to examine the mediating effect of accumulated experience on the impact of epidemic experiences on farmers' biosecurity behavior [61]. The following regression model is constructed:

$$Bsb = c_1 Experiences + d_1 Controls + \mu_1 \tag{2}$$

$$M = aExperiences + d_2 Controls + \mu_2 \tag{3}$$

$$Bsb = c_2 Experiences + bM + d_3 Controls + \mu_3 \tag{4}$$

In the equation: *Bsb* represents farmers' biosecurity behavior, *Experiences* stand for epidemic experiences, *M* is the mediating variable, *Controls* denote the control variables, a, b, c_1, c_2 and $d_1 \sim d_3$ are the parameters to be estimated, and μ_1, μ_2 and μ_3 are the random error terms.

4. Results and analysis

4.1. Baseline results

Table 2 reports the impact of epidemic experiences on farmers' biosecurity behavior. The first column does not include control variables. Based on this, columns 2, 3, and 4 respectively introduce control variables such as personal and household characteristics, farming characteristics, and external characteristics. In the four models, the estimated coefficients of epidemic experiences are 0.230, 0.175, 0.128, and 0.129, all statistically significant at the 1% level. This indicates that epidemic experiences significantly promote farmers to implement biosecurity measures. As control variables are successively added, the estimated coefficient of epidemic experiences gradually decreases and tends to stabilize. In column 4, R^2 has increased after controlling for more variables. Therefore, the interpretation is based on the results in column 4. Farmers who have experienced an epidemic increase their biosecurity behavior by 0.129 units. Therefore, epidemic experiences have a significant promoting effect on farmers' biosecurity behavior. Hypothesis 1 is confirmed.

Table 2
Estimation results of epidemic experiences on farmer's biosecurity behavior.

	(1)	(2)	(3)	(4)
Epidemic experiences	0.230***	0.175***	0.128***	0.129***
	(0.030)	(0.029)	(0.030)	(0.030)
Age		-0.007***	-0.003*	-0.003*
		(0.002)	(0.002)	(0.002)
Education		0.016***	0.011**	0.011**
		(0.005)	(0.005)	(0.005)
Health		0.026	0.012	0.013
		(0.016)	(0.016)	(0.016)
Household main decision-makers		0.086***	0.089***	0.089***
		(0.027)	(0.026)	(0.027)
Number of farming labor			-0.009	-0.009
			(0.017)	(0.017)
Farming experience			-0.003***	-0.003***
			(0.001)	(0.001)
Farming scale			0.052***	0.053***
			(0.011)	(0.011)
Percentage of income from farming			-0.051	-0.054
			(0.046)	(0.047)
Type of pigpen			0.015	0.017
			(0.046)	(0.047)
Veterinary service organizations				-0.017
				(0.035)
Constant	0.207***	0.384***	0.153	0.156
	(0.017)	(0.129)	(0.153)	(0.153)
R^2	0.115	0.237	0.314	0.315

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively; the standard errors are in parentheses.

Regarding control variables, age has a negative impact on biosecurity behavior. When farmers are older, they tend to limit themselves to simple and less labor-intensive tasks. And their thinking is more conservative, which means they are unwilling to adopt biosecurity measures. Education appears to have a positive impact on biosecurity behavior. This indicates that farmers' education plays an important role in ensuring biosecurity. Farmers with higher education levels have more biosecurity knowledge and a more positive attitude [28], and therefore adopt more biosecurity measures. Households where important decisions are made jointly implement more biosecurity measures. The positive and significant coefficient of farm size means that farmers with larger production bases are willing to adopt more biosecurity measures. This may be because large-scale farmers can perceive greater risks and better understand the importance of prevention [16]. The coefficient of farming experience is negative and significant, indicating that the longer the farming experience, the less likely they are to adopt biosecurity measures. This may be because farmers are influenced by traditional farming habits and are accustomed to the existing farming model, they are unwilling to accept new concepts and technologies.

4.2. Further analysis

Different biosecurity measures have different characteristics, and the impact of epidemic experiences on them may be different. Therefore, this study separately analyzed the impact of epidemic experiences on the construction of segregation zones, changing clothes, and disinfection as three types of biosecurity measures. Among them, the construction of segregation zones and the changing of clothes are binary variables, and empirical analysis is carried out using probit model. Disinfection times is a continuous variable, and empirical analysis is carried out using ordinary least squares (OLS) method. As shown in Table 3, epidemic experiences have a significant positive impact on the three biosecurity measures. This indirectly verifies the robustness of the above results.

4.3. Endogeneity discussion

This study used propensity score matching (PSM) to reevaluate the impact of epidemic experiences on farmers' biosecurity behavior. This method can address endogeneity issues caused by observable variables. In order to obtain accurate estimates, this study employed three methods for matching: nearest neighbor matching, caliper matching, and kernel matching, to determine the differences in biosecurity measures implemented by farmers in the control group and the treatment group, known as the average treatment effect (ATT). The nearest neighbor matching used a standard of the nearest 4 units; caliper matching had a range of 0.06; and kernel matching used a default bandwidth of 0.06. Table 4 presents the estimated results of propensity score matching (PSM). The ATT values obtained from all three methods passed significance tests and showed consistent results. Farmers who experienced epidemics had a biosecurity level 0.150 higher compared to those who did not experience epidemics. Specifically, epidemic experiences significantly promoted farmers to construct segregation zones, change clothes, and conduct disinfection measures. These research results are highly consistent with previous estimates, even in the face of potential selection bias.

4.4. Mechanism analysis

After confirming the positive correlation between epidemic experiences and biosecurity behavior, we further explored the underlying mechanism. According to the theoretical analysis in the previous section, epidemic experiences may promote farmers' biosecurity behavior by increasing their accumulated experience. Table 5 presents the results of mechanism analysis. The results indicate that epidemic experiences significantly enhance farmers' accumulated experience, thus promoting the implementation of biosecurity measures by farmers. Specifically, epidemic experiences, through accumulated experience, promote farmers to establish quarantine zones, change clothes, and disinfect. Accumulated experience plays an intermediate role in the impact of epidemic experiences on farmers' biosecurity behavior. Hypothesis 2 is verified. As mentioned in Section 2, farmers who have experienced epidemics have a more comprehensive understanding of disease symptoms, risks, and the importance of biosecurity measures. Compared to farmers who have not experienced epidemics, they have a richer experience in epidemic prevention and control. The experience helps farmers effectively improve biosecurity of their farms to prevent the impact of other epidemics.

Table 3
Estimated results of the impact of epidemic experiences on three biosecurity measures.

	Segregation	Changing clothes	Disinfection
Epidemic experiences	0.507***	0.444***	0.678***
	(0.163)	(0.144)	(0.212)
Control variables	Yes	Yes	Yes
Constant	-0.027	-2.874***	-1.718*
	(0.852)	(0.840)	(1.003)
R^2	–	–	0.187
pseudo R^2	0.200	0.330	–

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively; the standard errors are in parentheses.

4.5. Heterogeneity analysis

This study has demonstrated a positive correlation between epidemic experiences and farmers' biosecurity behavior. However, due to the significant differences among pig farmers, whether this relationship has been established remains to be explored. This study analyzes the heterogeneous impact of epidemic experiences on biosecurity behavior from the perspective of farming scale. Drawing on the research of Xu et al. [62], farmers are divided into two categories: small-scale farmers (less than 50 heads) and professional farmers (more than 50 heads). Table 6 shows the results of group heterogeneity. Overall, epidemic experiences have a significant promoting effect on biosecurity behavior of both types of farmers, but the impact is stronger for professional farmers. Specifically, in terms of establishing segregation zones and changing clothes, epidemic experiences have significantly promoted both types of farmers' biosecurity behavior. However, this impact is slightly stronger for professional farmers than for small-scale farmers. For disinfection measures, the estimated coefficient of epidemic experiences is significantly positive for professional farmers at the 1% statistical level. However, the estimated coefficient did not show statistical significance for small-scale farmers. These findings suggest that professional farmers benefit more from epidemic experiences than small-scale farmers. This can be explained by the fact that professional farmers have larger farming scales, and their household income mainly depends on pig farming, so they attach more importance to the epidemics. They have improved their awareness of epidemic prevention and risk perception by accumulating relevant biosecurity knowledge and drawing lessons from disasters related to diseases. Therefore, they are more willing to adopt more biosecurity measures.

5. Discussion

In recent years, China's pig industry has frequently suffered from various animal diseases outbreaks. Biosecurity is the key to successful pig production during outbreaks [5]. It is of significant practical importance for ensuring healthy development of the pig farming industry and stabilizing farmers' income. As mentioned earlier, the impact of farmers' epidemic experiences on their biosecurity behavior has not received attention from the academic community. Given the importance of the pig industry in China, we believe that exploring the impact of epidemic experiences on farmers' biosecurity behavior is essential. Therefore, this study starts with protection motivation theory (PMT) and creates a theoretical framework to explain how epidemic experiences affect farmers' biosecurity behavior. In this framework, we propose two pathways: direct impact and accumulated experience impact.

Firstly, our research results indicate that epidemic experiences significantly promote farmers to implement biosecurity measures. This finding is consistent with Delpont et al. [63], demonstrates that farms with recent outbreaks of highly pathogenic avian influenza have higher levels of biosecurity. Similar studies have also obtained the same results. Botzen et al. found that experience with COVID-19 is an important factor in adopting preventive behavior [64]. Farmers who have experienced previous epidemics such as African swine fever have a better understanding of infectious diseases and disease prevention measures, they are more sensitive to animal disease risks. They can implement biosecurity measures earlier and adapt better to subsequent outbreaks. Farmers should try to avoid the impact of epidemics as much as possible, although it may be challenging to avoid them altogether. If farmers are inevitably affected by epidemics, they should take it seriously and see it as a valuable experience from which to learn and improve.

Next, we analyzed the underlying mechanism to explore how epidemic experiences effect farmers' biosecurity behavior. The mechanism analysis indicates that epidemic experiences increase farmers' accumulated experience, thereby promoting their biosecurity behavior. Specifically, epidemic experiences may enhance farmers' perceived severity of threat, perceived susceptibility, self-efficacy, and response

Table 4
PSM model estimation results.

Variables	Methods	Treatment group	Control group	ATT	S.D.	T value
Biosecurity behavior	K-nearest neighbor matching	0.437	0.271	0.167***	0.041	4.10
	Radius matching	0.437	0.295	0.142***	0.038	3.75
	Kernel matching	0.437	0.297	0.140***	0.039	3.58
	K-nearest neighbor matching	0.315	0.151	0.164***	0.050	3.29
Segregation	Radius matching	0.315	0.181	0.134***	0.047	2.85
	Kernel matching	0.315	0.173	0.142***	0.048	2.93
	K-nearest neighbor matching	0.607	0.417	0.191***	0.062	3.06
Changing clothes	Radius matching	0.607	0.428	0.180***	0.056	3.19
	Kernel matching	0.607	0.449	0.159***	0.058	2.72
	K-nearest neighbor matching	4.097	3.343	0.755**	0.316	2.39
Disinfection	Radius matching	4.097	3.582	0.516*	0.281	1.83
	Kernel matching	4.097	3.569	0.528*	0.292	1.81

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

Table 5
Epidemic experiences and biosecurity behavior: Mechanism analysis.

Variables	Accumulated experience	Biosecurity behavior	Segregation	Changing clothes	Disinfection
	OLS	OLS	Probit	Probit	OLS
Epidemic experiences	0.179***	0.107***	0.426***	0.392***	0.572***
	(0.048)	(0.030)	(0.165)	(0.146)	(0.213)
Accumulated experience		0.115***	0.621***	0.371**	0.593***
		(0.028)	(0.148)	(0.151)	(0.197)
Control variables	Yes	Yes	Yes	Yes	Yes
R^2	0.314	0.340	–	–	0.202
pseudo R^2	–	–	0.230	0.340	–

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively; the standard errors are in parentheses.

Table 6
Heterogeneity analysis results.

Variables	Biosecurity behavior		Segregation		Changing clothes		Disinfection	
	Professional farmers	Small-scale farmers	Professional farmers	Small-scale farmers	Professional farmers	Small-scale farmers	Professional farmers	Small-scale farmers
Epidemic experiences	0.183***	0.103***	0.692***	0.453**	0.513**	0.434**	1.278***	0.361
	(0.052)	(0.033)	(0.261)	(0.216)	(0.247)	(0.185)	(0.317)	(0.267)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	183	293	183	293	183	293	183	293
R^2	0.269	0.233	–	–	–	–	0.375	0.161
pseudo R^2	–	–	0.256	0.213	0.249	0.198	–	–

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively; the standard errors are in parentheses.

efficacy. This partly confirms previous research findings that suggest that risk perception of diseases and understanding the effectiveness of biosecurity measures are crucial factors influencing farmers' implementation of biosecurity measures [24,58,65]. If farmers have a good understanding of the impact of diseases and the best practices of biosecurity, they will be willing to enhance biosecurity on their farms to prevent epidemic outbreaks. Therefore, the government should focus on technical training, education, promotion, and other measures to explain the serious threats posed by diseases and the importance and effectiveness of biosecurity measures in reducing risks.

Furthermore, we focus on the heterogeneity of epidemic experiences in terms of farming scale. We found that compared to small-scale farmers, epidemic experiences have a stronger promoting effect on biosecurity behavior of professional farmers. There are two main reasons for this: firstly, professional farmers have larger scales of farming and higher stocking densities, making their farms more susceptible to animal infectious diseases. Moreover, once an epidemic occurs, the farm will suffer a devastating blow, leading to significant economic losses for farmers. Therefore, professional farmers place a greater emphasis on epidemics, actively learning from these experiences to better cope with the next epidemic. This is consistent with conclusions from some studies, such as farmers with larger production bases may perceive greater risks and thus have a better understanding of the importance of prevention [16]. Large-scale poultry farmers have a higher perception of vulnerability and response efficacy, leading them to adopt more biosecurity measures [65]. Secondly, the investment required to implement biosecurity measures on farms is costly in financial costs and efforts [66]. Despite farmers believing in the economic benefit of disease prevention, they consider the response cost of disease prevention measures to be quite high [21]. Therefore, professional pig farmers benefit from economies of scale and lower unit costs of biosecurity prevention and control, enabling them to invest more in biosecurity. In contrast, small-scale farmers lack resources and are unable to put their knowledge into practice. Even experience is not enough to persuade small-scale farmers to do things that are financially unfeasible for them. Several studies have also proven this point, for example, response cost of integrated pest management hinder farmers' adoption of IPM [46]. High perceived cost associated with adaptation measures significantly reduce farmers' willingness to implement such measures [67]. This highlights the importance of reducing the adoption costs of biosecurity measures.

Lastly, some limitations of this study deserve attention. Firstly, although this study conducted detailed production surveys of Chinese pig farmers, the sample size was limited by survey costs. In addition to pigs, other animals such as poultry, cattle, and sheep are also affected by animal diseases. The impact of epidemic experiences on biosecurity behavior may vary across different animals. In future research, it is necessary to expand the scope of the survey to include a broader range of animals (such as chickens, ducks, cattle, and sheep) to assess the comprehensive impact of epidemic experiences on farmers' biosecurity behavior. Secondly, although this study has carefully addressed endogeneity of epidemic experiences and reduced endogeneity bias, limitations due to cross-sectional data cannot rule out endogeneity issues potentially caused by some unobserved factors. In future research, panel data can be used to verify and enhance the generalizability of the research results.

6. Conclusions and policy implications

This research built a theoretical framework based on PMT and utilized the survey data from pig farmers in China's main pig production areas to analyze the impact and mechanism of epidemic experiences on farmers' biosecurity behavior. The main conclusions are as follows: firstly, epidemic experiences significantly promote farmers to implement biosecurity measures. This conclusion remains robust after addressing potential endogeneity issues. Secondly, epidemic experiences promote farmers to implement biosecurity measures by increasing accumulated experience. Thirdly, the impact of epidemic experiences on biosecurity behavior among farmers shows heterogeneity in terms of farming scale. Compared to small-scale farmers, epidemic experiences have a greater promoting effect on professional farmers.

Based on the research conclusions above, this study provides the following policy implications. Firstly, based on the discovery that epidemic experiences promote biosecurity behavior, farmers should value their own epidemic experiences. Farmers should face epidemic experiences optimistically, actively learn from them, and better prepare for other epidemics. Secondly, based on the research result that epidemic experiences can increase accumulated experience, agricultural policies should utilize these relationships. The government should enhance the promotion of animal infectious disease knowledge, strengthen disease prevention and control technical training, and improve pig farmers' awareness of disease prevention and biosecurity management. Thirdly, the heterogeneity results indicate that farming scale is an important factor in implementing biosecurity measures. Policy initiatives can focus on promoting biosecurity measures suitable for small-scale farms. Additionally, by lowering the implementation cost of biosecurity measures through price support, it can promote the purchase of inputs such as segregation zones and disinfectants.

CRediT authorship contribution statement

Wenying Zhang: Writing – original draft, Visualization, Methodology, Data curation, Conceptualization, Formal analysis, Software. **Qian Lu:** Writing – review & editing, Supervision, Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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