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Game analysis on the quality and safety control of pork supply chain – The case study of China

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Abstract: Using the method of static game analysis, the potential risk and responsibility across the entire pork supply chain are discussed from the perspective of all stakeholders involved. Included in the analysis are pig suppliers, slaughterers, pork processors, pork sellers and consumers. The results indicate the following: firstly, the lower the probability of inspections on downstream businesses and the higher the single inspection fee, the greater the probability of harmful substances used by upstream businesses and the higher the costs. Secondly, businesses that actively manufacture and transfer harmful substances in the supply chain cannot add extra costs. Finally, the quality and risk factors in pork production may not follow a strictly linear growth. This study might explain the unique problems that occur in pork supply chain management in large developing countries such as China.

Keywords: allocation of risk and responsibility; risk control; stakeholders of pork supply chain; static game analysis

China is the largest pork producer and consumer in the world. The country's pork production exceeded 50 million tons for the first time in 2010 and peaked at 58.21 million tons in 2014 (52.24% of total world production), followed by a small decline thereafter (USDA 2022). On the consumption side, China nearly maintained total self-sufficiency until 2015 (Han et al. 2022). Affected by the African swine fever (ASF) and the COVID-19 pandemic, China's pork imports doubled between 2015 and 2016 and then rose to double digits in 2020 (12.72% of total domestic consumption). Overall, China's pork production and consumption maintain a stable trend. However, in recent years, the frequent occurrence of quality and safety issues with pork products has reduced Chinese consumer confidence, which is mainly reflected in the excessive or illicit use of additives in feed and veterinary medicines and the sale of sick pigs and water-injected pork by fraud or deception. Simultaneously, various factors such as production costs, price fluctuations, changes in eating habits, and national environmental protection policies also affect the quality and safety of the pork supply chain. All these factors have led to heightened concerns about food safety issues.

From the perspective of modern economics, the essence of food quality and safety issues is information asymmetry (Caswell et al. 1998), which may lead to increasing marketing costs and loss of producer or consumer interests (Eugenio et al. 2017). The pork supply chain, generally organised as a linear system with a strong link structure, which may include breeding, slaughter, processing, pork sales, feed, and veterinary drug supply. Given the nature of the swine industry, the production risk of each link in the pork supply chain is closely related to people's food safety (Trienekens and Wognum 2013; Gunnarsson et al.

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2020; Green-Miller et al. 2021). Related research shows that approximately 90% of pork quality and safety incidents have resulted from human factors, such as violations by supply chain participants (Wu et al. 2017). Therefore, strengthening the management of various participants is the key to reinforcing safety and risk control in the pork supply chain (Abrudan et al. 2022).

In researching the quality and safety of the pork supply chain, scholars have different views on the distribution of responsibility among the main participants of the pork supply chain. Some scholars believe that pig farmers, as the front end of the pork supply chain, should take the main responsibility for pork quality and safety (Leikas et al. 2009; Henderson et al. 2010). Similar to the research conclusion of Osadchiy et al. (2016), the risk in the upstream supply chain is directly related to the stability of the entire supply chain network structure. Some believe that the slaughtering and processing link is the core of the entire pork supply chain, which connects pig suppliers and sellers, and has a higher risk and speed of infection (Cai et al. 2020). Simultaneously, the storage and transportation links run through the whole process of the pork supply chain and should also be supervised and managed as the focus of risk control. Research by Wu et al. (2017) shows that the designation of responsibility for ensuring pork quality and safety was of, in descending order, feed producers and suppliers, pig farmers, pork processors, slaughterhouses, supermarkets, farmers' markets, pig transporters, and consumers. In short, the main participants that are directly involved in the initial pork supply chain should take greater responsibility for pork quality and safety. As the supervisor of the pork supply chain, the government does not directly participate in pork production. Its responsibility is to clarify and supervise the respective legal responsibilities of the government, pork producers, and consumers through legislation and regulation of pork production, management, and consumption activities. Research by Harray et al. (2018) shows the importance of government involvement in the regulation of an environmentally sustainable food supply. At the end of the supply chain, consumers generally have a low degree of participation in the supply chain, but the plans and behaviours of production are closely related to consumers' satisfaction, willingness to pay, consumption habits, and preferences. Related research shows that with increasing awareness of issues of environmental protection, consumers have higher trust in food with certification logos and a relatively high willingness to pay for pork (Wang et al. 2018; Santeramo and Lamonaca 2021). These forces from the market will transmit the shock to the upstream supply chain (Assefa et al. 2017), thereby affecting and changing the behaviour of upstream subjects.

Based on the analysis of each link of the pork supply chain and the behaviour of the main stakeholders, scholars have also conducted further discussions on the management and construction of the pork supply chain in various countries. The way out is to regard pork production as a chain rather than a single step (Perez et al. 2009), integrate information technology, logistics management, and quality management (Han et al. 2009), and enhance the supply chain's ability to resist risk shocks through vertical collaboration between the main participants and horizontal cooperation between members within the main body to build a stable, resilient, and sustainable pork supply chain to improve overall competitiveness (Taylor 2006; Perez et al. 2010; Leat and Revoredo-Giha 2013; Labrecque et al. 2015). More importantly, improving the traceable production system to realise the supervision and traceability of pork from the field to the table guarantees the trust of consumers (Xiong et al. 2007; Chen et al. 2020).

In general, the relevant researches on the pork supply chain are relatively abundant, but most of them are segmented research. Scholars alike generally study issues of safety in terms of one or various links, such as pig breeding, slaughtering, storage and transportation, market demand, and government supervision. However, they have rarely discussed the quality and safety control of the pork supply chain incorporating all links into a whole systematic analysis, particularly from the perspective of game theory. Food quality and safety are closely dependent on the behaviour of each subject in the entire supply chain, from production and processing to sales. Successful supply chain management will enable enterprises and individuals in the chain to be in a strategic alliance of benefit sharing and realise information sharing. To provide guarantees for improving services, reducing costs, and integrating logistics, there must be cooperation and competition between each subject in this process. Game theory can be used to analyse the behaviour of different subjects when dealing with quality and safety issues. The game relationship between the quality and safety of agricultural products determines the final result of the quality of the agricultural products provided.

This paper redresses the problem above by examining issues of quality and safety within each step of the pork supply chain, using methods of static game analysis. The results of game balance can provide theoretical support to downstream businesses intending

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to increase the ability to intercept risk in the supply chain to mitigate damage by providing reference points to design safety policies and punishment for non-compliance. In applying this approach, greater safety in pork supplies and greater control over the supply chain can be achieved.

MATERIALS AND METHODS

Broadly, the scope of the pork supply chain can be extended beyond the areas already discussed to cover the production of veterinary drugs, feed and additives, the manufacture of equipment used for breeding, slaughtering, processing and distributing pig products, the refrigerating houses used to keep the frozen meat market supply and demand in balance, and government departments and consumers. For convenience, this paper assumes that the pork supply chain covers five participants that share direct correlations with all types of pork safety risks, including the pig suppliers, slaughterers, pork processors, and pork sellers and consumers. Other links are considered to be external to the supply chain and are not discussed in this paper. When the quality and safety risks of pork products are spread back along the supply chain, the general flow of actions taken by each participant is shown in Figure 1.

Referring to the current literature on the game analysis of food safety, this paper constructs a static game model about the five players above (Song and Zhuang 2017; Wang et al. 2021; Peng et al. 2022). To facilitate the discussion, this paper assumes the indexes as follows: i, j (i, j = 1, 2, 3, 4, 5) represent each business node in the pork supply chain (specifically, 1 – pig supplier, 2 – pig slaughterer, 3 – pork seller, 4 – pork processor, and 5 – consumer). R_i is the normal income of the business node in the pork supply chain, $R_i^{'}$ is the supernormal income of the business node, and p is the probability of using harmful substances, where the supernormal income of the business node is greater than the normal income ($R_i^{'} > R_i$). The business has the motivation to produce and transmit harmful substances and spread quality and safety risks to the downstream links of the industry chain. C is the cost to the business on the inspection of pork products, and q is the inspection probability. If the pork fails the inspection, the business will lose all income in the current period of the operating cycle. Moreover, it is assumed that the business can quickly rectify the problem and resume operations such that future income is not affected. However, if this business node does not check upstream products of the industry chain, it may transfer the pork quality and safety risks passively. S represents the loss of consumers, in other words, the costs of hospitalisation and other direct losses caused by the consumption of harmful pork in cases where the consumer does not check for unsafe products. The risk transfer factor for quality and safety, which is the probability of using harmful substances by all upstream nodes before the current business node, is represented by α. The safety supervision interceptor, which is the probability of inspecting product quality by all upstream nodes before the current business node, is represented by β.

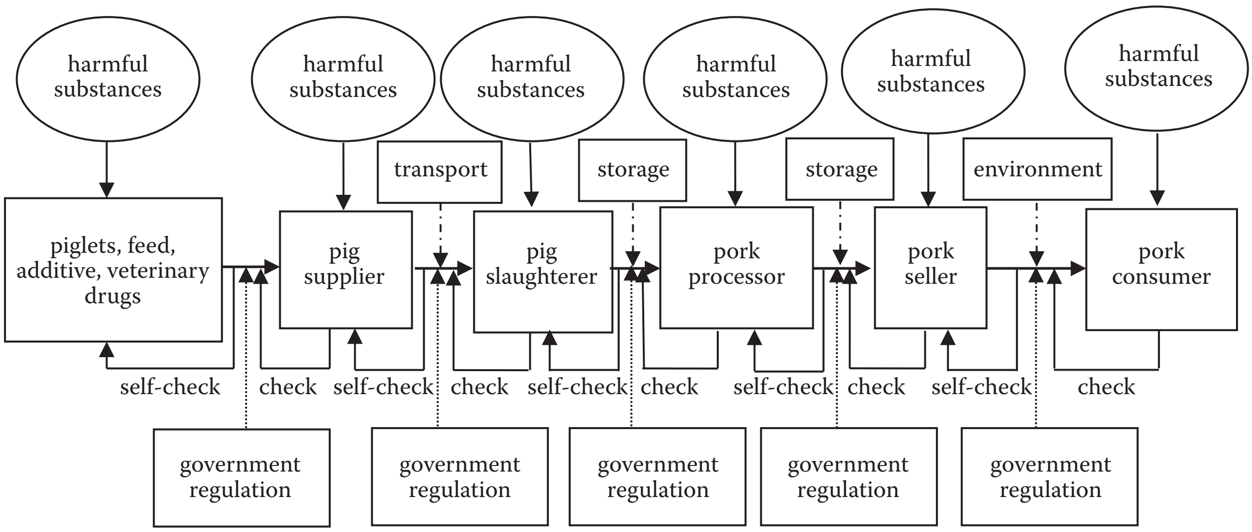

Figure 1. General flow of the backwards spread of quality and safety risks in the pork supply chain

Source: Authors' own elaboration

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RESULTS AND DISCUSSION

According to the Nash theorem, the quality and safety control of the pork product supply chain can be analysed through four game models. This paper assumes that all the models are static. In other words, a business node does not know whether other business nodes use harmful substances. Therefore, this model inevitably has only the Nash equilibrium of a mixed strategy.

Static game analysis between pig suppliers and slaughterers. The static game matrix of mixed strategies for pig suppliers and slaughterers is shown in Table 1.

The revenue function for pig suppliers and slaughterers is as follows:

$$\pi_1 = \left(1 - p_1\right)R_1 + p_1\left(1 - q_2\right)R_1^{'} \tag{1}$$

$$\pi_2 = q_2\left(R_2 - C_2\right) + \left(1 - p_1\right)\left(1 - q_2\right)R_2 + p_1\left(1 - q_2\right)\left(1 - q_3\right)R_2 \tag{2}$$

where: p – probability of using harmful substances; q – inspection probability; R_i – normal income of the business node in the pork supply chain; $R_i^{'}$ – supernormal income of the business node; C – cost to the business on the inspection of pork products.

Assuming that $\partial\pi_1/\partial p_1 = 0$, the mixed strategy Nash equilibrium for the solution is:

$$q_2 = \frac{R_1^{'} - R_1}{R_1^{'}} \tag{3}$$

Assuming that $\partial\pi_2/\partial p_2 = 0$, the mixed strategy Nash equilibrium for the solution is as follows:

$$p_1 = \frac{C_2}{R_2} \times \frac{1}{q_3} \tag{4}$$

The above parameters result in the profit functions:

$$\pi_1 = R_1 \tag{5}$$

$$\pi_2 = R_2 - C_2 \tag{6}$$

The biggest risk factor for pig slaughterers is as follows:

$$\alpha_2 = p_1 \tag{7}$$

The intercept risk factor for pig slaughterers is as follows:

$$\beta_2 = q_2 \tag{8}$$

Static game analysis between pig slaughterers and pork processors. The static game matrix of mixed strategies for pig slaughterers and pork processors is shown in Table 2.

The revenue function for pig slaughterers and pork processors is as follows:

$$\pi_2^{'} = \left(1 - p_2\right)\left(1 - q_3\right)R_2 + p_2\left(1 - q_3\right)R_2^{'} + \left(1 - p_1\right)\left(1 - p_2\right)q_3R_2 \tag{9}$$

$$\pi_3 = q_3\left(R_3 - C_3\right) + \left(1 - q_3\right)\left(1 - q_4\right)R_3 + \left(1 - p_1\right)\left(1 - p_2\right)\left(1 - q_3\right)q_4R_3 \tag{10}$$

Assuming that $\partial\pi_2^{'}/\partial p_2 = 0$, the mixed strategy Nash equilibrium for the solution is:

$$q_3 = \frac{R_2^{'} - R_2 + C_2}{R_2^{'}} \tag{11}$$

Assuming that $\partial\pi_3/\partial q_3 = 0$, the mixed strategy Nash equilibrium for the solution is as in Equation (12).

Table 1. Pig suppliers' and slaughterers' static game matrix of mixed strategies

Main body		Slaughterer	
Supplier	probability	check (q_2)	no check ($1 - q_2$)
Use	p_1	0, $(R_2 - C_2)$	$R_1^{'}$, $R_2(1 - q_3)$
No use	$(1 - p_1)$	R_1, $(R_2 - C_2)$	R_1, R_2

q – inspection probability; p – probability of using harmful substances; R_i – normal income of the business node in the pork supply chain; $R_i^{'}$ – supernormal income of the business node; C – cost to the business on the inspection of pork products
Source: Authors' own processing

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Table 2. Pig slaughterers' and pork processors' static game matrix of mixed strategies

Main body			Processors	
			check (q_3)	no check ($1 - q_3$)
Supplier	slaughterer	probability		
Use	use	p_1, p_2	0, ($R_3 - C_3$)	$R_2^{'}$, $R_3(1 - q_4)$
No use	use	$(1 - p_1), p_2$	0, ($R_3 - C_3$)	$R_2^{'}$, $R_3(1 - q_4)$
Use	no use	$p_1, (1 - p_2)$	0, ($R_3 - C_3$)	$R_2^{'}$, $R_3(1 - q_4)$
No use	no use	$(1 - p_1), (1 - p_2)$	R_2, ($R_3 - C_3$)	$R_2^{'}$, R_3

q – inspection probability; p – probability of using harmful substances; R_i – normal income of the business node in the pork supply chain; $R_i^{'}$ – supernormal income of the business node; C – cost to the business on the inspection of pork products
Source: Authors' own processing

$$p_2 = \frac{C_3 - p_1 q_4 R_3}{\left(1 - p_1\right) q_4 R_3} \quad (12)$$

The above parameters result in the profit functions:

$$\pi_2^{'} = R_2^{'}\left(1 - q_3\right) = R_2 - C_2 \quad (13)$$

$$\pi_3 = R_3 - C_3 \quad (14)$$

The biggest risk factor for pork processors is as follows:

$$\alpha_3 = 1 - \left(1 - p_1\right)\left(1 - p_2\right) \quad (15)$$

The intercept risk factor for pork processors is as follows:

$$\beta_3 = 1 - \left(1 - q_2\right)\left(1 - q_3\right) \quad (16)$$

Static game analysis between pork processors and sellers. The static game matrix of mixed strategies for pork processors and sellers is shown in Table 3.

The revenue function for pork processors and sellers is as follows:

$$\pi_3^{'} = \left(1 - p_3\right)\left(1 - q_4\right)R_3 + p_3\left(1 - q_4\right)R_3^{'} + \\ + \left(1 - p_1\right)\left(1 - p_2\right)\left(1 - p_3\right)q_4 R_3 \quad (17)$$

$$\pi_4 = q_4\left(R_4 - C_4\right) + \left(1 - q_4\right)\left(1 - q_5\right)R_4 + \\ + \left(1 - p_1\right)\left(1 - p_2\right)\left(1 - p_3\right)\left(1 - q_4\right)q_5 R_4 \quad (18)$$

Assuming that $\partial\pi_3^{'}/\partial p_3 = 0$, the mixed strategy Nash equilibrium for the solution is:

$$q_4 = \frac{R_3^{'} - R_3 + C_3}{R_4^{'}} \quad (19)$$

Assuming that $\partial\pi_4/\partial q_4 = 0$, the mixed strategy Nash equilibrium for the solution is:

$$p_3 = 1 - \frac{R_3\left(R_3^{'} - R_3 + C_3\right)}{\left(R_3 - C_3\right)\left(R_3^{'} - R_3\right)} \times \frac{q_5 R_4 - C_4}{q_5 R_4} \quad (20)$$

The above parameters result in the profit functions:

$$\pi_3^{'} = R_3^{'}\left(1 - q_4\right) = R_3 - C_3 \quad (21)$$

$$\pi_4 = R_4 - C_4 \quad (22)$$

The biggest risk factor for pork sellers is as follows:

$$\alpha_4 = 1 - \left(1 - p_1\right)\left(1 - p_2\right)\left(1 - p_3\right) \quad (23)$$

The intercept risk factor for pork sellers is as follows:

$$\beta_4 = 1 - \left(1 - q_2\right)\left(1 - q_3\right)\left(1 - q_4\right) \quad (24)$$

Static game analysis between pork sellers and consumers. The static game matrix of mixed strategies for pork sellers and consumers is shown in Table 4.

The revenue function for pork sellers and consumers is as in Equations (25, 26).

$$\pi_4^{'} = \left(1 - p_4\right)\left(1 - q_5\right)R_4 + p_4\left(1 - q_5\right)R_4^{'} + \\ + \left(1 - p_1\right)\left(1 - p_2\right)\left(1 - p_3\right)\left(1 - p_4\right)q_5 R_4 \quad (25)$$

$$\pi_5 = q_5\left(R_5 - C_5\right) - \left(1 - q_5\right)S + \left(1 - p_1\right)\left(1 - p_2\right)\left(1 - p_3\right)\left(1 - p_4\right)\left(1 - q_5\right)\left(R_5 + S\right) \quad (26)$$

where: S – loss of consumers.

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Assuming that $\partial\pi_4^{'}/\partial p_4 = 0$, the mixed strategy Nash equilibrium for the solution is:

$$q_5 = \frac{R_4^{'} - R_4 + C_4}{R_4^{'}} \quad (27)$$

Assuming that $\partial\pi_5/\partial q_5 = 0$, the mixed strategy Nash equilibrium for the solution is:

$$p_4 = 1 - \frac{R_5 - C_5 + S}{R_5 + S} \times \frac{R_4\left(R_4^{'}R_4 + C_4\right)}{\left(R_4 - C_4\right)\left(R_4^{'} - R_4\right)} \quad (28)$$

The above parameters result in the following profit functions:

$$\pi_4^{'} = R_4^{'}\left(1 - q_5\right) = R_4 - C_4 \quad (29)$$

$$\pi_4 = R_5 - C_5 \quad (30)$$

The biggest risk factor for pork consumers is as follows:

$$\alpha_5 = 1 - \left(1 - p_1\right)\left(1 - p_2\right)\left(1 - p_3\right)\left(1 - p_4\right) \quad (31)$$

The intercept risk factor for pork consumers is as follows:

$$\beta_5 = 1 - \left(1 - q_2\right)\left(1 - q_3\right)\left(1 - q_4\right)\left(1 - q_5\right) \quad (32)$$

Discussion. In terms of the relationship between the income of upstream businesses in the pork supply chain and the inspection probability of downstream businesses, Equations (1, 2, 9, 10, 17, 18, 25, 26) indicate that the lower the inspection probability of the downstream enterprise, the higher the expected income of the upstream enterprises. When the terminal consumer market in the industry chain does not inspect the safety of fresh pork, all upstream business nodes will ignore the product inspection and use harmful substances to obtain a higher income. Consequently, this will form a security risk to the upward nodes that eliminates safety across the entire supply chain of pork. Therefore, market regulators should strengthen supervision over the terminal market of the pork supply chain. It is only in this manner that businesses can spontaneously build a supervision and control mechanism in the pork supply chain – that is, a typical terminal-drive mechanism.

In terms of the relationship between the supernormal income of upstream businesses in the pork supply chain and the inspection probability, Equations (3, 11, 19, 27) indicate that the higher the supernormal income upstream businesses gain from the use of harmful substances, the greater the probability of downstream businesses to inspect the pork safety as they must ensure their earnings. In practice, the greater the supernormal income that businesses can obtain, the higher the probability of the businesses adopting improper means. Therefore, market regulators should focus on supervising businesses that use harmful substances to obtain supernormal income. They should improve the inspections and the penalty costs for illegal practices, which will help to block harmful substances at the source.

In terms of the relationship between the probability of using harmful substances by upstream busi-

Table 3. Pork processors' and sellers' static game matrix of mixed strategies

Main body				Sellers	
Supplier	slaughterer	processor	probability	check (q_4)	no check ($1 - q_4$)
Use	use	use	p_1, p_2, p_3	0, $(R_4 - C_4)$	$R_3^{'}$, $R_4\,(1 - q_5)$
Use	no use	use	p_1, $(1 - p_2)$, p_3	0, $(R_4 - C_4)$	$R_3^{'}$, $R_4\,(1 - q_5)$
No use	use	use	$(1 - p_1)$, p_2, p_3	0, $(R_4 - C_4)$	$R_3^{'}$, $R_4\,(1 - q_5)$
No use	no use	use	$(1 - p_1)$, $(1 - p_2)$, p_3	0, $(R_4 - C_4)$	$R_3^{'}$, $R_4\,(1 - q_5)$
Use	use	no use	p_1, p_2, $(1 - p_3)$	0, $(R_4 - C_4)$	$R_3^{'}$, $R_4\,(1 - q_5)$
No use	use	no use	$(1 - p_1)$, p_2, $(1 - p_3)$	0, $(R_4 - C_4)$	$R_3^{'}$, $R_4\,(1 - q_5)$
Use	no use	no use	p_1, $(1 - p_2)$, $(1 - p_3)$	0, $(R_4 - C_4)$	$R_3^{'}$, $R_4\,(1 - q_5)$
No use	no use	no use	$(1 - p_1)$, $(1 - p_2)$, $(1 - p_3)$	R_3, $(R_4 - C_4)$	R_3, R_4

q – inspection probability; p – probability of using harmful substances; R_i – normal income of the business node in the pork supply chain; $R_i^{'}$ – supernormal income of the business node; C – cost to the business on the inspection of pork products
Source: Authors' own processing

Table 4. Pork sellers' and consumers' static game matrix of mixed strategies

Main body					Consumers	
					check (q_5)	no check ($1 - q_5$)
Supplier	slaughterer	processor	seller	probability		
Use	use	use	use	p_1, p_2, p_3, p_4	$0, (R_5 - C_5)$	$R_4^{'}, -S$
No use	use	use	use	$(1 - p_1), p_2, p_3, p_4$	$0, (R_5 - C_5)$	$R_4^{'}, -S$
Use	no use	use	use	$p_1, (1 - p_2), p_3, p_4$	$0, (R_5 - C_5)$	$R_4^{'}, -S$
Use	use	no use	use	$p_1, p_2, (1 - p_3), p_4$	$0, (R_5 - C_5)$	$R_4^{'}, -S$
No use	no use	use	use	$(1 - p_1), (1 - p_2), p_3, p_4$	$0, (R_5 - C_5)$	$R_4^{'}, -S$
No use	use	no use	use	$(1 - p_1), p_2, (1 - p_3), p_4$	$0, (R_5 - C_5)$	$R_4^{'}, -S$
Use	no use	no use	use	$p_1, (1 - p_2), (1 - p_3), p_4$	$0, (R_5 - C_5)$	$R_4^{'}, -S$
No use	no use	no use	use	$(1 - p_1), (1 - p_2), (1 - p_3), p_4$	$0, (R_5 - C_5)$	$R_4^{'}, -S$
Use	use	use	no use	$p_1, p_2, p_3, (1 - p_4)$	$0, (R_5 - C_5)$	$R_4^{'}, -S$
No use	use	use	no use	$(1 - p_1), p_2, p_3, (1 - p_4)$	$0, (R_5 - C_5)$	$R_4^{'}, -S$
Use	no use	use	no use	$p_1, (1 - p_2), p_3, (1 - p_4)$	$0, (R_5 - C_5)$	$R_4^{'}, -S$
Use	use	no use	no use	$p_1, p_2, (1 - p_3), (1 - p_4)$	$0, (R_5 - C_5)$	$R_4^{'}, -S$
No use	no use	use	no use	$(1 - p_1), (1 - p_2), p_3, (1 - p_4)$	$0, (R_5 - C_5)$	$R_4^{'}, -S$
No use	use	no use	no use	$(1 - p_1), p_2, (1 - p_3), (1 - p_4)$	$0, (R_5 - C_5)$	$R_4^{'}, -S$
Use	no use	no use	no use	$p_1, (1 - p_2), (1 - p_3), (1 - p_4)$	$0, (R_5 - C_5)$	$R_4^{'}, -S$
No use	no use	no use	no use	$(1 - p_1), (1 - p_2), (1 - p_3), (1 - p_4)$	$R_4, (R_5 - C_5)$	R_4, R_5

q – inspection probability; p – probability of using harmful substances; R_i – normal income of the business node in the pork supply chain; $R_i^{'}$ – supernormal income of the business node; C – cost to the business on the inspection of pork products; S – loss of consumers

Source: Authors' own processing

nesses in the pork supply chain and the inspection cost of downstream businesses, Equations (4, 12, 20, 28) indicate that the higher the inspection cost paid by downstream businesses, the higher the probability of using harmful substances by upstream businesses. In practice, downstream businesses are reluctant to pay high inspection costs, thus lowering the inspection probability. As such, upstream businesses have a loophole to exploit. Therefore, as individual consumers cannot afford the inspection fee, market regulators should impose mandatory inspections and strict supervision over product safety in the terminal market, or the government can provide subsidies for inspection fees and develop more convenient, low-cost detection equipment.

In terms of the relationship between the operating means of each business node in the pork supply chain and the enterprise income, Equations (5, 6, 13, 14, 20, 21, 29, 30) indicate that actively producing and delivering fresh pork products with harmful substances cannot bring extra income to the business node. Under the supervision of the inspection mechanism, the business node can only receive the expected return under normal circumstances or even fail to receive the normal income. Meanwhile, the use of harmful substances by upstream businesses in the pork supply chain would reduce the normal income of downstream businesses and the utility of terminal consumers. Therefore, various participants in the pork supply chain should undertake legitimate means of operation and actively assume regulatory responsibility to gain maximum corporate profits.

In terms of the risk transfer factor for quality and safety and the safety inspection interceptor for each business node in the pork supply chain, Equations (7, 8, 15, 16, 22, 23, 31, 32) indicate that the risk transfer factor does not necessarily show a linear increase. In other words, the risk transfer factor does not have a fixed growth rate. If $\beta_i > \alpha_i$, fresh pork is generally safe before slaughter link, if $\beta_i \leq \alpha_i$, there will be security risks. In the case that each node in the pork supply chain has an inspection mechanism, the risk transfer factor may remain unchanged or decrease with an increase in the inspection probability. However, when the inspection probability of a node drops, the risk factor of this node will increase. Therefore, the closer the node is to the end of the pork supply chain, the greater the risk associated with this node. Termi-

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nal businesses should improve their ability to intercept risks and mitigate harm.

In terms of the relationship between the overall income in the pork supply chain and the operating means for each business node, if $p_i = 0(i = 1, 2, 3, 4, 5)$ and $q_j = 0(j = 1, 2, 3, 4, 5)$, pork products are qualified in the production flow and the total revenue of the supply chain is:

$$\left[\sum_i R_i\left(i=1,2,3,4,5\right)\right];$$

if $p_i \neq 0(i = 1, 2, 3, 4, 5)$ and $q_j = 0(j = 1, 2, 3, 4, 5)$, then the total revenue of the supply chain is:

$$\left[\sum_i R_i^{'}\left(i=1,2,3,4,5\right)\right];$$

if $p_i = 0(i = 1, 2, 3, 4, 5)$ and $q_j \neq 0(j = 1, 2, 3, 4, 5)$, then the total revenue of the supply chain is:

$$\left[\sum_i R_i-\sum_j C_j\left(i,j=1,2,3,4,5\right)\right];$$

if $p_i \neq 0(i = 1, 2, 3, 4, 5)$ and $q_j \neq 0(j = 1, 2, 3, 4, 5)$, then the total revenue of the supply chain is:

$$\left[\sum_i R_i^{'}-\sum_j C_j\left(i,j=1,2,3,4,5\right)\right].$$

CONCLUSION

Subsequent to the game analysis among the main participants of the supply chain, we realised whether pork can safely reach consumers from the source of production depends on the behaviour and coordination of all entities in the chain. If upstream businesses in the pork supply chain engage in improper means of operation and no supervision is exercised on the chain downstream, the overall income of the whole pork supply chain is strictly greater than the normal income. If upstream businesses engage in improper means of operation, but supervision is exercised in the chain downstream, the difference between the overall income of the whole pork supply chain and the normal income is the cost of supervision, that is:

$$\left[-\sum_j C_j\left(j=1,2,3,4,5\right)\right].$$

Therefore, all the nodes in the pork supply chain should run the industry according to the law and share the risks and benefits to ensure that the entire pork supply chain can obtain the greatest benefit. The validated conclusions outlined above can contribute to and assist in emerging policy enlightenment. Firstly, explore the construction of a green and sustainable pork supply chain. Improve animal welfare, and pursue organic while considering the balance between environmental, economic, and social sustainability (Maples et al. 2019; Zira et al. 2021). Secondly, build a pattern of social pluralism and co-governance. It is essential to innovate the supply chain management model, encourage multiple parties to supervise, and have equal sharing of interests and risks (Zhuo et al. 2021). Thirdly, improve the construction of an agricultural product traceability system. This is a current deficiency in China. It is necessary to fill the legal gaps related to traceability as soon as possible, and establish a unified information management platform covering the whole area from the field to the table so that force the main participants of the pork supply chain to strictly follow the standard and standardised production. Finally, strengthen education and training for pig farmers to avoid breeding and production risks from the source. Specialised and commercial productions are gaining importance, although small-scale (backyard) pig production still dominates production in China (Ji et al. 2012). One of the challenges in the standardisation of breeding specialisation is that pig farmers have limited access to safety production information and high costs. In this regard, the Chinese government should develop moderate-scale breeding, strengthen education and training for small- and medium-sized farmers, and provide policy and financial support in environmental protection and technical guidance.

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