Examine the Impacts of the Coronavirus Crisis on Vegetable Pricing

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Abstract: Vegetables, as a necessity of people's lives, are of great concern to the community in terms of their price changes. Vegetable prices have experienced significant fluctuations under the tremendous impact of the New Crown epidemic. Using the theoretical approach rooted in the principles of evolutionary game theory to evaluate and map out the strategic interactions between vegetable growers and distributors. It provides an in-depth examination of how the pandemic has influenced the availability and distribution of these vital goods, and based on the relevant literature, puts forward countermeasure suggestions to maintain the stability of vegetable prices. Studying the fluctuation pattern of vegetable prices under the influence of the epidemic has far-reaching and important significance and value for guaranteeing market supply, safeguarding consumers' rights and interests, improving farmers' income as well as precisely regulating the market. Through rigorous research and analysis, this article can respond more effectively to to the swiftly shifting market conditions during health emergencies and promote the sustainable prosperity of the market.

1 INTRODUCTION

The cost of perishable goods is significantly linked to public well-being and is essential for maintaining balance and fostering long-term development within the broader socio-economic system. Maintaining fresh commodities is particularly important for the healthy development of society, and in recent years, the e-commerce sector for fresh food in China has experienced a significant surge in growth. In 2022, the revenue from online transactions of perishable goods in China reached 363.75 billion yuan, representing a 16.7% rise from the prior year. The COVID-19 outbreak has notably boosted the public's online purchasing behavior for fresh produce, enhancing their reliance on e-commerce platforms specializing in fresh foods. Forecasts suggest that by 2026, the market for fresh foods in China could expand to 630.20 billion yuan. (iResearch, 2024).

Meanwhile, according to Shenggen Fan (2021), the Food and Land Use Coalition estimates that the environmental, health, and social costs amount to at least $12 trillion per year, a figure that exceeds the value of the food system's global output. This suggests that the food system, including fresh commodities, is a significant part of the global economy and that its impacts extend far beyond direct economic transactions The price volatility of fresh commodities, as an important part of the socio-economic fabric and a necessity of people's lives, is widely publicized. However, the outbreak of the New Crown epidemic has created unprecedented challenges for society as a whole, including the agricultural sector.

The New Crown epidemic significantly influenced every phase of the vegetable distribution network, and vegetables have received much attention from the community due to the significant changes in pricing dynamics following the outbreak, this study aims to delve into the complex interplay of factors affecting the pricing of vegetables following COVID-19. The early stages of the epidemic led to widespread disruptions in labor supply, particularly in the labor-intensive vegetable farming industry. Blockades and mobility restrictions prevented the movement of seasonal workers, leading to labor shortages that directly affected the harvesting and processing of vegetables. These disruptions led to higher production costs, which inevitably led to higher prices for consumers. According to Alam, G. M. M., & Khatun, M. N. (2021) found that due to the perishable nature of vegetables, small-scale vegetable

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growers are particularly affected. The blockade restricted the ability of vegetable growers to reach marketplaces, consequently constraining their ability to produce and sell. In addition, the outbreak triggered a surge in demand for vegetables, with consumers engaging in panic buying and hoarding to ensure food security. This sudden surge in demand, coupled with a reduced supply chain due to operational challenges, created an imbalance between supply and demand that exerted upward pressure on vegetable prices. Not only that the impact of COVID-19 was not limited to production and demand but also extended to the logistics and transportation sectors. Disruptions in these sectors have resulted in higher transportation costs to move vegetables from farm to market. Border closures and restrictions have also affected the import and export of vegetables, leading to localized shortages and price volatility in different regions. At the same time, government policies and interventions have played a key role in shaping vegetable pricing patterns. Export bans, import restrictions and incentives aimed at supporting farmers and the agricultural sector directly and indirectly affected vegetable pricing. Epidemics highlight the importance of resilient and adaptive food supply chains, and of effective policy responses to mitigate pricing impacts and ensure food safety (OECD, 2020).

By applying the principles of evolutionary game theory, this study develops a model of strategic interactions that encompasses producers and retailers to simulate the strategic choices of both parties under the influence of the New Crown epidemic and its impact on vegetable pricing, to provide insights into the impact of the New Crown epidemic on the pricing of vegetable-based commodities and examine the factors that lead to price volatility. By understanding these dynamics, policymakers, and stakeholders can develop strategies to stabilize vegetable prices and increase the resilience of the food system to future crises.

2 LITERATURE REVIEW

The outbreak of the Xinguan epidemic had a major impact on the pricing of vegetable commodities due to the following aspects. In terms of market behavior, it was found that the blockade policy led to significant increases in vegetable prices and increased price dispersion, reflecting the severe disruption of the distribution network. With respect to specific categories, Ruan, Cai, and Jin (2021) the price of Chinese cabbage increased by about 46% after the outbreak blockade and peaked in the fourth week of the blockade, subsequently experienced a steady decrease. Research revealed that amidst the restrictions imposed by the COVID-19 pandemic, there was a notable upsurge in the costs of wheat flour, referred to as atta, and rice within the Indian market. In contrast, the cost of onions saw a significant drop. The price increases may be related to increased demand or supply shortages, while the price decreases in onions may be related to their semi-perishable nature. GU & WANG (2020) examined the effects of the health crisis on the cultivation of vegetables by conducting questionnaires and oral inquiries. with 46 agricultural cooperatives in Shanghai and showed that several segments of the vegetable supply chain were affected due to the blockade and self-isolation policies stemming from the COVID-19 outbreak. Particularly during the cultivation and distribution stages, labor shortages and reduced transport efficiency led to increased costs. At the same time, the vulnerability to market fluctuations in the cultivation of vegetables has risen. significantly during the New Crown epidemic. Consequently, the disparity in pricing from the farm gate to the marketplace has expanded. This indicates that the uncertainty and risk of the supply chain increased, making the selling price higher (Gu & Wang, 2020).

In this paper, the authors use evolutionary game theory to study the vegetable pricing problem, which was pioneered by von Neumann and Morgenstern within the realm of economic theory (von Neumann and Morgenstern, 1994) John Nash (Nash, 1950) and Lloyd Shapley (Shapley, 1953) further developed this theory, laying down the foundation of the modern noncooperative The cornerstone of modern non-cooperative game theory was laid. Next, evolutionary game theory incorporates population ecology. In this perspective, participants are understood to be finitely rational and pursue evolutionarily stable strategies through repeated experimentation, imitation, and learning.

Game theory is often used in the study of vegetable supply chains, Mousapour Mamoudan et al. (2022) used game theory to study game theory models showing how to develop pricing strategies for perishable food products taking into account brand value and competitors' prices and how to optimize supply chain coordination through quantity discount contracts. It is constructed as a game model of the fresh food supply chain incorporating techniques for initial cooling and the mitigation of greenhouse gas emissions. Exploring the Impact of Energy-Efficient and Emission-Reducing Technologies on the

Sustainability of Fresh Food Distribution Networks (Liu, Huang, Shang, Zhao, Yang, & Zhao, 2022). Omkar D. Palsule-Desai in his study also used a game theory model to study the rationalization of fruit and vegetable cooperatives in India and the impact and stability of decentralization (Palsule-Desai, 2015).

3 MODEL BUILDING

As a static idea evolutionary stable strategy is the basic concept of evolutionary game, which can describe the basic stability of the existence of a dynamic system. Evolutionary game theory highlights the concept of bounded rationality in the decision-making process, that the main body involved in the game theory is finite rationality of both sides, their behavior and choice will be in the process of continuous change, and ultimately tends to be constantly stable, the main body of the game for the vegetable is the producer of A, and vegetable retailers B, as finite rationality of the main body, participants in the process of the mature strategy respectively, the producer of the vegetable commodity supply chain strategies to give Producer's strategy in the vegetable commodity supply chain is to give "high price" and "low price"; retailer's strategy in the vegetable commodity supply chain also has to give "high price" and "low price". The retailer's strategic choices in the vegetable commodity supply chain are also "high price" and "low price".

x denotes the probability that the producer gives a high price, 1-x denotes the probability that the producer gives a low price; The variable 'y' represents the likelihood of a retailer setting a high price for their goods, whereas '1-y' corresponds to the chance that they opt for a lower pricing strategy.; R1 denotes the producer's revenue, C1 denotes the producer's cost, R2 denotes the retailer's revenue, C2 denotes the retailer's cost. The cooperation between the two parties results in a synergistic revenue value P. The additional revenue value is allocated according to the participation ratio. The producer's allocation ratio is a, and the value of the additional gain is denoted as aP, while the retailer's allocation ratio is (1-a), and the additional gain is (1-a)P, where $0 \leqq a \leqq 1$.

Among them, the producer's revenue R1 includes sales and government subsidies, and producer's costs include vegetable planting costs, such as seeds, pesticides, land, transportation and logistics costs; the retailer's revenue R2 mainly includes sales, and the retailer's costs C2 include purchasing costs, transportation costs, storage costs, and operating costs, for the producer's additional revenue aP is the stabilization of the sales channel, i.e., the establishment of stable cooperative relationships with retailers, which also includes the reduction of market risks, and the reduction of market risks. cooperative relationship, also includes the reduction of market risk, producers through cooperation with retailers, producers can diversify the production risk, through the retailer's diversified sales to help producers in different markets and consumer groups; for the retailer's additional benefits (1-a) P embodied in the stability of the supply chain, cooperation with the producer can ensure the stability of the supply of vegetables to mitigate the impact of seasonal or other factors.

4 INTEREST MATRIX AND EVOLUTIONARY MODELING

The strategic outcomes matrix for the grower and the seller in the bilateral interaction game is presented in Table 1 below.

Table 1: Translation of the Payoff Matrix in the Game between Manufacturer A and Retailer B.

Event	Producer cooperation	Non-cooperation of producers
Vendor Collaboration	$R_2+(1-a)P-C_2$ R_1+aP-C_1	R_2-C_2 R_1
Uncooperative vendors	R_2 R_1-C_1	R_2 R_1

Based on assumptions in Table 1, the expected and average returns when producer B adopts the "cooperative" and "uncooperative" strategies are U_{11}、U_{12} and U_1 respectively, which are determined using the subsequent methodology:

$$U_{11}=y(R_1+aP-C_1)+(1-y)(R_1-C_1)=yaP+R_1-C_1 \tag{1}$$

$$U_{12}=yR_1+(1-y)R_1=R_1 \tag{2}$$

$$U_1=xU_{11}+(1-x)U_{12}=x(yaP-C_1)+R_1 \tag{3}$$

Replication dynamic equation are equations that model the rate at which a collective embraces particular strategies amidst evolving conditions. The replication dynamic equation for the evolutionary game with probability x that a producer chooses to "cooperate" is:

$$F_A(x)=\frac{dx}{dt}=x(U_{11}-U_1)=x(1-x)(aPy-C_1) \tag{4}$$

The anticipated and mean profits when the vendor implements "cooperative" and "uncooperative" strategies are U_{21}, $U_{22}$and U_2respectively, which are determined using the subsequent methodology：

$$U_{21} = x(R_2 + (1-a)P - C_2) + (1-x)(R_2 - C_2) = x(1-a)P + R_2 - C_2 \quad (5)$$

$$U_{22} = xR_2 + (1-x)R_2 = R_2 \quad (6)$$

$$U_2 = yU_{21} + (1-y)U_{22} = y(x(1-a)P - C_2) + R_2 \quad (7)$$

The formula that describes the replication dynamics for a vendor opting to engage in a "collaborative" approach with a given likelihood y is:

$$F_B(y) = \frac{dy}{dt} = y(U_{21} - U_2) = y(1-y)((1-a)Px - C_2) \quad (8)$$

When F_A(x)=F_B(y)=0the equilibrium points can be derived from A(0,1),B(0,0),C(1,0),D(1,1)and E($\frac{C_2}{(1-a)P}$, C_1/aP).

According to Friedman's theory, by replicating the system of dynamic equations in trial (4), the Jacobi matrix can be obtained as Table 2.

Based on the stipulated premise, the significance of both the starting and the resulting points is confined to a plane with two axes$V = \{(x,y)|0 \ll x \ll 1, 0 \ll y \ll 1,\}$ Noting that The determinant of the matrix is represented as det(J), while the sum of the diagonal elements is denoted by tr(J); the evaluation of stability for the five points of equilibrium is detailed in Table 2.and evolutionary stabilization points for both sides of the game can be seen in table 3.

$$\begin{cases} detJ = \frac{\partial F(x)}{\partial x} * \frac{\partial F(y)}{\partial y} - \frac{\partial F(x)}{\partial y} \times \frac{\partial F(y)}{\partial x} & (9) \\ trJ = \frac{\partial F(x)}{\partial x} + \frac{\partial F(y)}{\partial y} & (10) \end{cases}$$

Table 2: Jacobi matrix determinant values and traces for each equilibrium point.

equilibrium points	detJ	trJ
(0,0)	C_1C_2	$C_1 - C_2$
(0,1)	$C_2(aP - C_1)$	$C_1 + C_2 - aP$
(1,0)	$C_1(C_2 - (1-a)P)$	(1 − a)P $- C_1 - C_2$
(1,1)	$(C_1 - aP)$((1-a)P-C_2)	$(2a - 1)P + C_2 - C_1$
(x_0, y_0)	$[\frac{C_2}{(1-a)P\left(\frac{C_2}{(1-a)P}-1\right)aP}]\ [\frac{C_1}{aP(\frac{C_1}{aP}-1)(1-a)P}]$	0

Table 3: Evolutionary stabilization points for both sides of the game.

equilibrium points	detJ notation	trJ notation	Equilibrium results
(0,0)	+	-	ESS
(0,1)	+	+	point of instability
(1,0)	+	+	point of instability
(1,1)	+	-	ESS
(x_0, y_0)	+	x	saddle point

From the analysis of the graph, (0,0) and (1,1) are the ESS equilibrium points, indicating that both producers and retailers choose "no cooperation" or "cooperation" and the evolutionary phase diagram of manufacturer A and retailer B can be seen in figure 1.

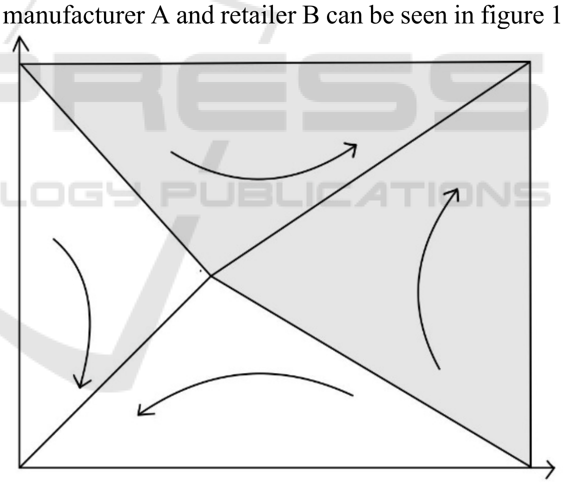

Figure 1: Evolutionary Phase Diagram of Manufacturer A and Retailer B. (Picture credit: Original).

The coordinates B(0,0) and D(1,1) represent two points of equilibrium that emerge as stable solutions, signifying that both producer and marketer replication dynamic curves converge to these two point locations. When both imitators' dynamic curves converge to B(0,0), producers and marketers do not cooperate to become the norm, and when both imitators' dynamic curves converge to point D(1,1), producers and marketers cooperate to become the norm, in which point E is the key point for judging that the two simulated dynamics trajectories coalesce at points B and D. And the final direction of the game is related to the area $S_1$of ABCE and the areaS_2 of AECD, when $S_1 < S_2$ both participants in the strategic interaction are inclined to collaborate as the outcomes develop, when$S_1 > S_2$, the two participants in the strategic interaction are inclined to select the path of non-cooperation in the evolution of the analysis of the factors affecting the size of the area of $S_2$is shown below:

$$S_2 = 1 - 1/2[\frac{C_2}{(1-a)P} + C_1/aP] \tag{11}$$

From the formulaS_2, it can be seen that the image S_2area size of the parameters areC_1、C_2、a、P, with S_2on these parameters for the partial derivation, "+" indicates a positive correlation, "-" indicates a negative correlation, "*" indicates that can not discern correlation, the results are shown in Table 4. "*" indicates that the correlation cannot be discerned, and the results are obtained as shown in Table 4:

Table 4: Analysis of the influence of parameters on the choice of cooperative strategies of the game-participating subjects.

parameters	partial derivative	Effect on S_2
C_1、C_2	<0	-
a	*	*
P	>0	+

As can be seen from Table 4, the cost of producers and retailers choosing to cooperate with C_1、$C_2$and $S_2$is negatively correlated, that is, when choosing a cooperative strategy, when the mutual collaboration expenses surpass a specific threshold, it will make both sides to obtain the benefits of less than the cost, which leads to the two sides to choose the strategy of non-collaboration.

a and (1-a) are the proportion of collaboration benefit distribution of producers and retailers, respectively, where the range of a is [0, 1] but the effect on the size of the area of S_2 cannot be judged.

P is the collaboration benefit of producers and retailers choosing cooperation strategy, aP and (1-a)P are the amount of benefit distribution between the two parties respectively, when P increases it will have a positive correlation on the area of S_2, which can be obtained that with the increase of the collaboration benefit, the stability and attractiveness of the cooperation between the producers and retailers are enhanced. This implies that increasing the benefits of cooperation not only promotes the growth of both parties' revenues but also strengthens their cooperative relationship, making cooperation a preferred strategic choice for both parties. This positive correlation also implies that through an appropriate benefit distribution mechanism, both parties can be incentivized to seek more efficient ways of cooperation, thus jointly expanding the revenue space.

5 SUGGESTIONS

5.1 Increased Transparency in the Vegetable Supply Chain

Supply chain transparency helps to stabilize vegetable supply and thus stabilize vegetable prices According to the results of this paper, the cooperation between producers and sellers has an important impact on the stable supply of vegetables, and on the cooperation between the two sides, through the transparent supply chain management, vegetable producers can have a clearer understanding of the costs of planting, picking, transportation and other links, which helps to carry out cost control and management. This can help producers avoid unnecessary waste and extra costs, thus stabilizing production costs and influencing the final selling price fluctuations. At the same time, a transparent supply chain in producer-retailer cooperation enables producers, wholesalers, and retailers to better understand market demand and supply, so that they can adjust production and inventory more effectively and keep supply in balance with demand. When supply and demand are stabilized, vegetable price volatility may be reduced.

Enhancing the openness within the vegetable distribution network can be realized through the utilization of advanced 5G and analytics technologies. By integrating 5G with data analytics, supply chain managers can access and analyze data from all parts of the supply chain in real-time, thus achieving higher transparency and efficiency, Combining 5G and Big Data, supply chain managers can access and analyze data from all parts of the supply chain in real time, thus achieving higher transparency and efficiency. For example, real-time data transmitted over 5G networks can be used to dynamically adjust vegetable production plans, optimize vegetable delivery routes, predict potential supply chain disruptions such as policy impacts under epidemics, vegetable demand impacts, etc., and take timely countermeasures (Bai & Sarkis, 2020). It is also possible to improve supply chain transparency by publicizing market information to consumers and establishing price indices to maintain stable supply relationships in response to the impact of public events such as epidemics on vegetable prices.

5.2 Controlling Costs for Producers and Distributors

Based on the findings from the strategic interaction analysis, between producers and retailers in this paper, the cost of both sides plays an important role in deciding whether to cooperate, so controlling the cost of both sides is better for maintaining supply and demand and thus stabilizing the price of vegetables, taking China as an example In China, the distribution cost of vegetable agricultural products accounts for 50%-60% of the selling price, or even higher. The reasons for this high cost include the inconsistency of transportation management around the world, which adds unnecessary costs to logistics enterprises, such as according to "The Paper "the different definitions of overloading in different provinces and the prevalence of indiscriminate fees and fines (2021). Therefore, optimizing the logistics and transportation of vegetable commodities can better control production costs.

Optimizing the logistics and transportation of vegetable commodities can enhance supply chain decision-making by employing digital twin technology how to predict the quality and marketability metrics of food in transit through real-time sensing and virtual models. According to "Innovation in Fruit and vegetable supply chains" Chandrima Shrivastava and colleagues at the University of Bern used digital twins to characterize the hot and humid conditions that preserve freshness, prevent infestation by fruit fly eggs, and steer clear of cooling system harm (2022). It is also possible to design different scenarios for fresh fruit and vegetable transportation and distribution networks employing Geographic Information Systems (GIS) for analysis. The research merged issues of site allocation with transportation routing via computational modeling to assess the efficacy of various scenarios. (Suraraksa & Shin, 2019).

5.3 Increase the Benefits of Collaboration Between Producers and Retailers

Based on the findings from the strategic interaction analysis, the collaborative revenue of producers and retailers significantly influences the collaborative decision-making process for both parties involved., so improving the collaborative revenue of the two parties can increase the probability of cooperation between the two parties and maintain the stability of the supply chain, thus making the price stable. The establishment of a long-term cooperative relationship can promote the trust between the two parties, reduce the conflict caused by the pursuit of short-term interests, and jointly respond to market changes to achieve long-term stable collaborative revenue, at the same time, improve the collaborative revenue, producers and retailers need to recognize and respect the retailers' anticipations regarding the equitableness of earnings allocation, through the profit distribution mechanism in the theory of the cooperative game to solve the problem (Zhang, Ma, Si, Liu, & Liao, 2011), which is the most important role in the decision-making of both parties. (Si, Liu, & Liao, 2021). It is also possible to help farmers improve their production skills, reduce costs, and improve product quality by collectively purchasing agricultural materials, sharing best practices and technologies, and providing training to increase the benefits of the collaboration or to help farmers obtain the necessary financial support through the establishment of a credit cooperation mechanism to reduce the production risk and improve the ability to adapt to market changes (Wang, Luo, & Liu, 2021).

6 CONCLUSION

This study offers a perspective on how the COVID-19 crisis has influenced the valuation of fresh produce, utilizing the principles of evolutionary strategic analysis. Taking vegetable producers and retailers as the two sides of the game and considering the influence of the outbreak on the distribution network of fresh produce resume evolutionary game model, the study finds that the epidemic leads to significant disruptions in all segments of the vegetable supply chain, especially labour shortage and logistics disruption, which together lead to significant fluctuations in vegetable prices. The evolutionary game model constructed in the article reveals the strategic choices of producers and retailers under the influence of the epidemic and their specific impacts on vegetable pricing, pointing out that the balance between cooperative and non-cooperative strategies plays an important role in price stability. This study examines how supply chain disruptions due to epidemics affect vegetable price volatility and proposes strategies to enhance supply chain resilience, which can help future research on how to maintain price stability in the face of similar crises fills a research gap on the relationship between price volatility as well as the adaptive capacity of the sequence of processes involved in the procurement, production, and distribution of goods.

The results of this research highlight the critical need for enhancing the clarity of supply chain operations, managing expenses, and boosting the mutual advantages derived from collaborative efforts among growers and sellers. These measures can be effective in stabilising vegetable prices and increasing the resilience of the supply chain, thus better coping with rapid changes in the market environment and possible future crises.

For the outlook of future research, the article suggests that it could further explore how technological innovations, technologies like 5G and advanced data analytics could potentially enhance both the openness and operational effectiveness of the supply chain oversight. Meanwhile, research could be extended to other types of agricultural products, as well as considering the impact of policies and market conditions on vegetable pricing in different regions and countries. In addition, future research could provide insights into the fairness of benefit distribution in cooperative mechanisms and how policy interventions can optimise the partnership between producers and retailers for the sustainability of the whole food system.

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