

# Mitigating Hoarding-Induced Chip Supply Chain Ripple Effect by Sourcing Optimisation Strategies

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**Abstract:** The semiconductor supply chain has faced serious shortages and delivery delays due to logistics disruption and trade conflicts, while panic hoarding behaviour has further exacerbated the risk of supply chain disruption. In this study, we conduct a simulation study based on the duopoly model under the condition of information asymmetry, combined with the Ouyang inventory model. The results show that when the information dissemination probability of supply shortage  $\alpha$  and the information dissemination probability of strong demand  $\beta$  are both high, the hoarding behaviour is more common, which can easily trigger supply chain disruption; however, if a certain proportion of core distributors choose not to hoard, the risk of supply chain disruption will be significantly alleviated. In addition, the analysis based on the supply chain game model shows that when the market is good, the distributors can obtain speculative gains by reducing supply, which may trigger systematic supply chain disruptions; while when the market is bad, the hoarding behaviour will exacerbate the losses, and it is necessary to increase the inventory turnover ratio in order to mitigate the losses. The empirical study further verifies that the impact of inventory turnover ratio on firms' net profit is significantly moderated by the market environment.

## 1. Introduction

In recent years, the Russian-Ukrainian war and the COVID-19 pandemic have had a far-reaching impact on the global landscape, the ability of supply chains to operate securely has become a national security issue, and once interrupted, it will have a major impact on the country's economy, social life and the stable development of the global industry. The global economy has suffered a severe impact. In the early stages of the pandemic, economic activity plummeted, supply chains nearly collapsed, and exports, investment and consumption were all significantly affected. With the stabilisation of outbreak prevention and control measures, the global economy has gradually recovered in the post-outbreak era, although supply chain disruptions are still not negligible.

As one of the most typical industries of globalisation, the chip industry has been particularly affected by the pandemic due to its highly segmented global division of labour and extended supply chain, with frequent problems such as surging demand, capacity constraints and prolonged delivery time. The specificity of the chip industry is reflected in the following aspects: first, it is both capital- and technology-intensive, and breaking through the core bottlenecks via technology transfer is extremely difficult, the only way to rely on independent research and development; second, the chip is closely related to the downstream manufacturing industry, and the disruption of its supply will have a cascading effect on many industries, which will affect the global economy; third, the global chip industry chain is widely distributed, and it is difficult for any one country to achieve the whole process of independent production.

The globalised nature of the chip supply chain makes it more politically sensitive. At present, China is mainly responsible for sealing and testing and other low-end links in the chip industry, and because of the dependence on imports of core technologies, especially high-end chips mostly relying on the U.S., China has limited bargaining power in the global chip supply chain, so the security of

the chip supply chain is in urgent need of enhancement. In the face of the complex international environment, especially the United States to promote the return of the manufacturing industry, to constrain China's technological development, the global supply chain security has been severely challenged to enhance the resilience of the chip supply chain has become an urgent task. With the accelerating technology iteration and the increasing demand for high-end chips, China's chip industry is facing "internal and external problems," and it is imperative to enhance the security of the industry chain and the ability of independent control.

## 2. Literature review

In recent years, the issue of supply chain disruptions has been widely studied in academia. After the outbreak of the COVID-19 pandemic, the risk of supply chain disruption has garnered increasing attention in the global research community to the topic. However, there is no uniform definition of supply chain disruption, and there are some differences in research paths and methods in academia. Zhang et al. empirically validated two distinct mitigation mechanisms - inventory control robustness and virtual dual sourcing - through comprehensive case analyses, demonstrating their efficacy in attenuating supply chain disruption impacts <sup>[1]</sup>. Nasir et al. pioneered an integrated decision-making framework synergizing Pareto analysis with grey system theory, specifically designed to enhance supply chain viability for SMEs during pandemic conditions <sup>[2]</sup>. Extending this research trajectory, Cao et al. conducted a game-theoretic investigation into blockchain implementation within semiconductor supply chains, employing a Stackelberg equilibrium model to quantify the dual effects of information transparency and cost-sharing contractual arrangements on both operational resilience and strategic decision-making paradigms <sup>[3]</sup>. Li et al. conducted a comprehensive analysis of blockchain-driven and data-driven strategies, examining their interdependencies with downstream service capacity saturation, upstream supply capacity constraints, market demand elasticity, and competitive pricing dynamics <sup>[4]</sup>. Hu et al. developed a stochastic optimization framework for contingency ordering under semiconductor supply chain disruptions, incorporating profit-maximization objectives <sup>[5]</sup>. Yu et al. formulated a tripartite closed-loop supply chain model within a Stackelberg game-theoretic framework, comprising manufacturers, e-commerce platforms, and third-party recyclers <sup>[6]</sup>.

In examining supply risk propagation, Rao and Goldsby conducted a systematic taxonomy of risk sources, categorizing them into four distinct dimensions: industrial, environmental, organizational, and issue-specific factors through comprehensive literature synthesis, while developing a managerial assessment protocol for early identification of supply chain vulnerabilities <sup>[7]</sup>. Sun advanced this discourse by proposing a novel analytical framework for critical metals that classifies risk factors along the supply chain continuum (upstream, midstream, downstream) while incorporating general systemic risks, particularly highlighting the research imperative for enhancing supply chain resilience to facilitate clean energy transitions <sup>[8]</sup>. Garvey et al. employed Bayesian network modeling to simulate risk propagation dynamics by explicitly accounting for interdependencies among heterogeneous risk sources and topological characteristics of supply network structures, with their computational experiments yielding actionable risk mitigation protocols <sup>[9]</sup>. Carnovale introduced a novel single-cycle kiddie model incorporating both exogenous and endogenous disruption risks, using Bayesian network simulations to derive optimal ordering strategies while demonstrating impact severity's contingency upon risk typology and supply chain architecture <sup>[10]</sup>. Hsu reconceptualized sustainable supply chain management as an integrated risk management process through developing objective decision frameworks and statistically-derived sentiment lexicons to quantify sustainability disclosure patterns and elucidate how supply chain efficiency mediates the profitability-firm valuation relationship, particularly in asset-intensive semiconductor industries <sup>[11]</sup>. Liao et al. conducted an empirical investigation utilizing partial least squares structural equation modeling to analyze survey data collected from 226 Chinese semiconductor downstream business managers. The study demonstrated that organizational capabilities in information system efficiency and flexibility, combined with risk management culture and mitigation competencies, significantly contribute to firm value creation through three critical mediating mechanisms: process optimization, risk mitigation

capacity enhancement, and supply chain flexibility improvement <sup>[12]</sup>. Yan et al. employed a Stackelberg game theoretic framework to systematically examine strategic decision-making paradigms during supply chain disruptions <sup>[13]</sup>. Wang et al. extended epidemiological modeling methodologies to supply chain risk analysis through the development of an advanced SEAIR model, building upon classical susceptible-infected-recovered frameworks <sup>[14]</sup>. Each factor exhibited statistically significant impacts on enterprise vulnerability profiles. Yao et al. pioneered an innovative risk propagation modeling approach integrating complex network theory foundations with Markov chain analytical processes <sup>[15]</sup>. Zhu et al. formulated a sophisticated weighted network susceptible-infected-treated-recovered propagation model, with subsequent parametric sensitivity analysis revealing recovery rates and infection probabilities as the dominant factors governing risk transmission dynamics within interconnected supply chain networks <sup>[16]</sup>.

In the study of information asymmetry in supply chain games, Esmaeili and Zeepongsekul developed an innovative upstream-downstream supply chain model that examines bilateral information asymmetry, where buyers possess private market demand information while sellers maintain confidential cost structures <sup>[17]</sup>. Avinadav and Shamir investigated inventory management strategies under conditions of unilateral information asymmetry, where retailers hold an informational advantage over suppliers regarding market conditions <sup>[18]</sup>. Dou et al. advanced the theoretical framework by constructing a sophisticated two-echelon supply chain game model involving four distinct stakeholders. This comprehensive model enabled systematic examination of three critical dimensions: the competitive dynamics between external suppliers and original equipment manufacturers, the strategic considerations underlying vertical integration decisions for manufacturing consortia, and the multivariate effects of profit differentials, technological competencies, and environmental factors on participant decision-making across various operational scenarios <sup>[19]</sup>.

In summary, the existing research in the field of supply chain disruption has the following characteristics: (1) for the study of disruption mechanisms, through combing the relevant literature found that most scholars like to conduct research through modelling simulation, combined with system dynamics, complex networks and other methods to explore the consequences caused by disruption as well as post-disruption treatment measures, etc.; (2) risk propagation research is mainly used in the Bayesian network, Markov chain, but the case study to describe risk propagation using actual data of the cause is relatively scarce; (3) information asymmetric game research focuses on the analysis of equilibrium solutions under demand information asymmetry, and mathematical modelling is dominated by the double oligopoly game.

### **3. Hoarding behaviour in a competitive duopoly market under information asymmetry**

#### **3.1. Problem description and underlying assumptions**

This paper constructs a basic model of a supply chain with one supplier and two distributors. Under normal circumstances, the supplier has sufficient production capacity and produces chips according to the orders of the downstream distributors, and the distributors place orders to the upstream supplier according to the downstream market demand. Speculative behaviour arises from multiple factors. Notably, market uncertainty and information asymmetry can significantly contribute to its emergence and additional uncertainties can further promote speculative behaviour. The global market conditions were volatile, information channels were blocked and the resulting asymmetry led to speculative behaviour in the supply chain, in addition, the interdependence of the uncertainty will also increase the probability of speculative behaviour. The use of coercive relationships by firms, such as threats, contractual provisions, etc., can lead to a greater tendency for partners to engage in speculative behaviour. Speculative behaviour can affect the price level by influencing the supply and demand relationship, impacting on production activities, affecting the operational efficiency of the supply chain, and causing supply disruptions in the supply chain if not stopped in time. Therefore, this paper proposes the following hypothesis:

**Assumption 1:** distributor 1 and distributor 2 are of different sizes and have different market

sizes  $D_1$ ,  $D_2$  respectively. The supplier's wholesale price to both distributors is  $\omega$ . The selling prices of the two distributors are  $p_1$  and  $p_2$  respectively.  $r_1$  and  $r_2$  denote the profits of the two distributors respectively, then there are  $p_1 = \omega + r_1$ ,  $p_2 = \omega + r_2$ . The market demand, i.e., the order quantity, of the two distributors is  $d_1$  and  $d_2$  respectively, and when both receive the signal to hoard, the quantity placed on the market is  $q_1$  and  $q_2$  respectively, and hence the quantity hoarded is  $d_1 - q_1$  and  $d_2 - q_2$  respectively.

**Assumption 2:** Assuming that there is an incomplete asymmetry of information between the internal and external markets, and that the internal members of the supply chain do not have access to all the information of the external market in a timely manner. Using  $x(x > 0)$  to indicate the external market situation, when  $x > 1$  indicates that there is a shortage of goods in the external market, the demand exceeds the supply;  $x < 1$  indicates that the demand in the external market is weak, the supply exceeds the demand. The speculative preference is denoted by  $\gamma$  and is satisfied by  $\gamma \in (0, 1)$ , which indicates the firm's preference for speculative behaviour. The magnitude of speculative preference is affected by the information asymmetry factor. It is assumed that the degree of information asymmetry is represented by the product of speculative preference and external market sentiment.

**Assumption 3:** Due to information asymmetry, firms that have access to external market conditions will engage in speculative behavioural considerations, and firms that do not have access to information, will not react. In this paper, it is assumed that distributor 1 is the party that gets speculative information, also known as the speculator, and when the conditions are right, it can take speculative behaviour and hoard. Distributor 2 is the information disadvantaged party and does not have access to information about changes in external market conditions and therefore will not engage in speculative hoarding behaviour.

The market demand function of distributor 1 is  $d_1 = D_1 - a(\omega + r_1) + b(\omega + r_2)$ , the market demand function of distributor 2 is  $d_2 = D_2 - a(\omega + r_2) + b(\omega + r_1)$ , according to assumption 3, so the supply quantity of distributor 2 is equal to the market demand quantity  $d_2$ . Where  $a$  represents the distributor's own price sensitivity coefficient,  $b$  represents the competitor's price sensitivity coefficient of demand that is the cross price sensitivity coefficient, this paper assumes that the distributor's own price sensitivity coefficient is not less than the cross price sensitivity coefficient of the competitors, that is  $a \geq b$ .

When the sensitivity coefficient of cross-price is larger that means to the two distributors of the distribution channel of the difference between the smaller, the more intense competition, the stronger the substitutability, on the contrary, when it is smaller, indicating that the two markets are less substitutable with each other, the competition is more peaceful. In the extreme case, when  $b = 0$ , indicating that the two markets do not exist on the price of substitution, the two market channels are independent of each other; when  $b = a$ , indicating that the two markets can be completely substitutable, the product can be completely substitutable, there is no difference.

### 3.2. Modelling and analysis

Assuming that costs are not considered in the model, the payoff function for distributor 1 is Eq. (1):

$$\pi_1 = r_1 q_1 + x \gamma r_1 (d_1 - q_1). \quad (1)$$

The payoff function for distributor 2 is Eq. (2):

$$\pi_2 = r_2 d_2. \quad (2)$$

The supplier's benefit function is Eq. (3):

$$\pi_s = \omega [D_1 + D_2 + (b - a)(2\omega + r_1 + r_2)]. \quad (3)$$

In Eq. (1) and Eq. (2),  $r_1 q_1$  and  $r_2 q_2$  denote the normal profit. Assuming that  $\pi_1' = r_1 q_1$  denotes the normal profit of distributor 1, the opportunity profit can be expressed as  $\pi_1'' = r_1 [D_1 - a(\omega + r_1) + b(\omega + r_2) - q_1](x_1 m - x_2 n)$ . In Eq. (3),  $D_1 + D_2 + (b - a)(2\omega + r_1 + r_2)$  denotes

the total demand of two distributors in the market. It is assumed that distributor 2 does not stock up, therefore, the market demand of distributor 2 is the supply.

### 3.2.1. Manufacturer Stackelberg two distributor Cournot competition model

The manufacturer Stackelberg two distributor Cournot competition model<sup>[20]</sup> is a model of a Cournot competition game where the supplier is the leader and the two distributors are the followers in the vertical direction and the two distributors are the Cournot competition game in the horizontal direction.

In this section, it is assumed that distributor 1 adopts hoarding behaviour and distributor 2 does not adopt hoarding behaviour. Hence,  $q_2 = d_2$ , implies that the supply of distributor 2 is equal to the order quantity and no hoarding occurs in between.  $d_1 - q_1$  denotes the quantity of goods hoarded by distributor 1.

The decision-making process is as follows: first, the manufacturer determines the wholesale price  $\omega$  with the objective of maximising its own profit; then, distributor 1 and distributor 2 simultaneously determine the profit per unit sold  $r_1$  and  $r_2$  with the objective of maximising their respective profits. Finally, the supplier determines a reasonable wholesale price  $\omega_{max}$  based on the objectives of  $r_1$  and  $r_2$  to maximise the supplier's profit.

Use backward induction to solve for the manufacturer's wholesale price and the unit sales profit decisions of the two distributors. First, the response functions of the unit sales profits of distributor 1 and distributor 2 are solved, i.e., the optimisation problem is solved. In this model, the profit functions of the two distributors are shown in Eq. (4) and Eq. (5), respectively:

$$\pi_1 = r_1 q_1 + \gamma x r_1 [D_1 - a(\omega + r_1) + b(\omega + r_2) - q_1]. \quad (4)$$

$$\pi_2 = r_2 (D_2 - a(\omega + r_2) + b(\omega + r_1)). \quad (5)$$

Theorem 3-1. In Eq. (4) and Eq. (5), for the supplier's given  $\omega$ , the two distributors can determine their respective profit functions per unit of product in their own self-interest-maximising situations as Eq. (6) and Eq. (7), respectively:

$$r_1 = \frac{2a q_1 (1-\gamma x)}{\gamma x (4a^2 - b^2)} + \frac{2a D_1 + b D_2}{(4a^2 - b^2)} - \frac{a-b}{2a-b} \omega. \quad (6)$$

$$r_2 = \frac{b q_1 (1-\gamma x)}{\gamma x (4a^2 - b^2)} + \frac{2a D_2 + b D_1}{(4a^2 - b^2)} - \frac{a-b}{2a-b} \omega. \quad (7)$$

Theorem 3-2. Based on the result of Theorem 3-1, there is the following conclusion:

The supplier gets the optimal wholesale price of  $r_1(\omega)$  and  $r_2(\omega)$ , as determined by the distributor: The optimal wholesale price for supplier is Eq. (8):

$$\omega_{max} = \frac{(D_1 + D_2)}{4(a-b)} - \frac{q_1(1-\gamma x)}{4a\gamma x}. \quad (8)$$

The optimal pricing for distributor 1 is Eq. (9):

$$p_1 = \frac{q_1(1-\gamma x)(6a^2 - ab)}{4a\gamma x(4a^2 - b^2)} + \frac{(10a^2 - 7ab)D_1 + (2a^2 + 5ab - 4b^2)D_2}{4(a-b)(4a^2 - b^2)}. \quad (9)$$

The optimal pricing for distributor 2 is Eq. (10):

$$p_2 = \frac{q_1(1-\gamma x)(-2a^2 + 3ab)}{4a\gamma x(4a^2 - b^2)} + \frac{(10a^2 - 7ab)D_2 + (2a^2 + 5ab - 4b^2)D_1}{4(a-b)(4a^2 - b^2)}. \quad (10)$$

The profit function for distributor 1 is Eq. (11):

$$\pi_1 = a\gamma \left[ \frac{q_1(1-\gamma x)(10a^2 - ab - b^2)}{4a\gamma x(4a^2 - b^2)} + \frac{(6a-b)D_1 + (3b-2a)D_2}{4(4a^2 - b^2)} \right]^2. \quad (11)$$

The profit function for distributor 2 is Eq. (12):

$$\pi_2 = a \left[ \frac{q_1(1-\gamma x)(2a^2 + 3ab - b^2)}{4a\gamma x(4a^2 - b^2)} + \frac{(6a-b)D_2 + (3b-2a)D_1}{4(4a^2 - b^2)} \right]^2. \quad (12)$$

The profit function of the supplier is Eq. (13):

$$\pi_s = \left[ \frac{(D_1+D_2)}{4(a-b)} - \frac{q_1(1-\gamma x)}{4a\gamma x} \right] \left[ \frac{a(D_1+D_2)}{2(2a-b)} - \frac{(a-b)q_1(1-\gamma)}{2\gamma x(2a-b)} \right]. \quad (13)$$

### 3.2.2. Distributor Stackelberg two distributor Cournot competition model

Distributor Stackelberg two distributor Cournot competition model is a game model in which the two distributors are leaders and the manufacturer is a follower in the vertical direction, and the two distributors are competing horizontally as Cournot.

The decision-making process is as follows: first, distributor 1 and distributor 2 simultaneously determine the unit sales profit  $r_1$  and  $r_2$ , respectively, with the objective of maximising their respective profits; then, the manufacturer determines the wholesale price  $\omega$  based on the determined  $r_1$  and  $r_2$ , with the objective of maximising its own profit. The manufacturer's optimal wholesale price and the two distributors' optimal unit sales profit are solved by using backward induction.

Theorem 3-3. Best wholesale price  $\omega$  is Eq. (14):

$$\omega = \frac{(3a-5b)D_1+(7a+b)D_2}{4(a-b)(5a-b)} - \frac{q_1(1-\gamma x)}{\gamma x(5a-b)}. \quad (14)$$

Distributor 1's profit per unit of product is Eq. (15):

$$r_1 = \frac{8q_1(3a+b)(1-\gamma x)}{\gamma x(7a+5b)(5a-b)} + \frac{(17a-9b)D_1+(7b-3a)D_2}{(7a+5b)(5a-b)}. \quad (15)$$

Distributor 2's profit per unit of product is Eq. (16):

$$r_2 = \frac{4q_1(1-\gamma x)(3b+a)}{\gamma x(7a+5b)(5a-b)} + \frac{(17a+3b)D_2-(3a+11b)D_1}{(7a+5b)(5a-b)}. \quad (16)$$

Because  $b > 0$ , so  $-(3a+11b) < 0$ , which means that distributor 2 own unit product profit and competitor's market size is inversely proportional to the competitor's market size, the larger the competitor's market size, their own unit product profit is smaller. As for distributor 1, its own profit per unit of product is directly proportional to its own market size and the market size of the other party.

Distributor 1's optimal pricing is Eq. (17):

$$p_1 = \frac{q_1(17a+3b)(1-\gamma x)}{\gamma x(7a+5b)(5a-b)} + \frac{(19a^2-23ab-8b^2)D_1+(23a^2+26ab-b^2)D_2}{2(a-b)(7a+5b)(5a-b)}. \quad (17)$$

The optimal pricing for distributor 2 is Eq. (18):

$$p_2 = \frac{q_1(7b-3a)(1-\gamma x)}{\gamma x(7a+5b)(5a-b)} + \frac{(19a^2-23ab-8b^2)D_2+(23a^2+26ab-b^2)D_1}{2(a-b)(7a+5b)(5a-b)}. \quad (18)$$

When  $\gamma x < 1$ , the supply quantity of distributor 1 is directly proportional to its own market pricing, at this time, the more supply quantity, the higher market pricing, but there is an upper limit of supply quantity. The supply volume of distributor 1 is inversely proportional to the market pricing of distributor 2. The more speculators supply, the lower the market pricing of distributor 2. Conversely, the more distributor 1 hoards, the higher the pricing of distributor 2.

### 3.2.3. Analysis of hoarding equilibrium points under information asymmetry

In the manufacturer-led Stackelberg-Cournot model of competition between two distributors, asymmetry information dissemination affects the magnitude of a firm's speculative preference, so that the hoarding trigger for distributor 1 is  $q_1 = \frac{a\gamma x((6a-b)D_1+(3b-2a)D_2)}{4(8a^2-2b^2)-(4-4\gamma x)(10a^2-ab-b^2)}$  at speculative preference and external market  $\in \left(\frac{1}{5}, +\infty\right)$ .

When  $q_1 < \frac{a\gamma x[(6a-b)D_1+(3b-2a)D_2]}{4(8a^2-2b^2)-(4-4\gamma x)(10a^2-ab-b^2)}$ , i.e. below this threshold, is jointly influenced by external market conditions and its own speculative preferences, speculative profit is higher than normal profit, indicating strong demand for chips, serious shortage of goods, speculative hoarding can obtain higher returns in the internal market, the smaller the supply quantity of distributors  $q_1$

means the smaller the supply quantity to the downstream, the larger the quantity of hoarding, the larger the opportunity profit is than the normal profit, and the higher the total profit is.

When  $q_1 > \frac{a\gamma x[(6a-b)D_1+(3b-2a)D_2]}{4(8a^2-2b^2)-(4-4\gamma x)(10a^2-ab-b^2)}$ , it means that the market demand is weak, the speculative profit is smaller than normal profit, the speculative return is low and the risk is high, the more the distributor's supply, i.e., the larger  $q_1$  is, and the smaller the hoarding  $d_1 - q_1$  is, the more favourable it is to maintain the normal profit.

## 4. Conclusion

### 4.1. Analysis of examples

To verify the validity of the duopoly competition model under information asymmetry, this paper conducts numerical simulation experiments using MATLAB. It analyses the distributor's supply volume, the three dimensions of information asymmetry (including their interaction), and examines their impacts on manufacturer's wholesale pricing, distributor's retail pricing, and the two types of profits (normal profits and speculative profits).

#### 4.1.1. Impact of distributor supply quantity on decision-making

The relationship between distributor 1's supply quantity and the manufacturer's wholesale price is shown in Figure 1. Setting speculative preferences at  $\gamma = 2$  and simulating two market scenarios, namely favourable ( $x = 0.7$ ) and weak ( $x = 0.4$ ), we examine the impact of distributor 1's supply quantity  $q_1$  on the manufacturer's wholesale price at  $\omega$ , the distributor's retail price  $p$ , and the resulting changes in profitability. The results show that when  $\gamma x > 1$ , the manufacturers moderately increase the wholesale prices as distributor 1's supply rises, due to speculative risk transfer considerations. Conversely, when  $< 1$ , manufacturers tend to reduce wholesale prices to encourage market circulation as supply increases. Regarding retail price, distributor-led structure yield lower price levels compared to the manufacturer-led structure, as distributors aim to maintain market share by accepting lower profit margins. In terms of profit, distributor 1 can achieve considerable speculative gains when supplying limited quantities, especially under the manufacturer-led structure. reducing supply and increasing stockpiling are necessary to prevent a drop in market prices. As illustrated in Figure 2, speculative profit can exceed normal profit when the supply is constrained. In this case, the speculative profit curve increases sharply and eventually exceeds the normal profit curve at a critical threshold, suggesting that it prefers to make inventory gains by reducing supply. This phenomenon suggests that under information asymmetry, supply quantity affects not only the market price mechanism but also the firm's profit structure. Therefore, setting supply levels appropriately becomes a key managerial tool to mitigate hoarding behaviour.

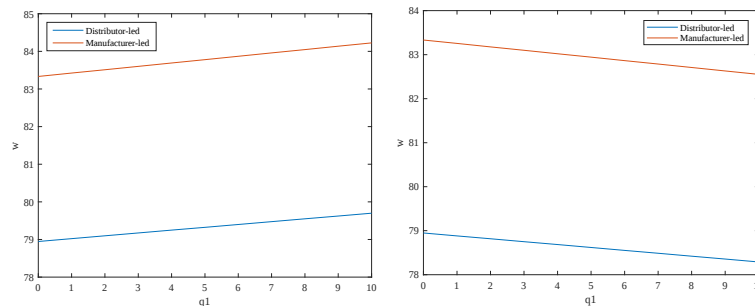


Figure 1. Impact of Distributor 1's supply quantity  $q_1$  on wholesale price  $\omega$  under  $\gamma x > 1$  and  $\gamma x < 1$ .

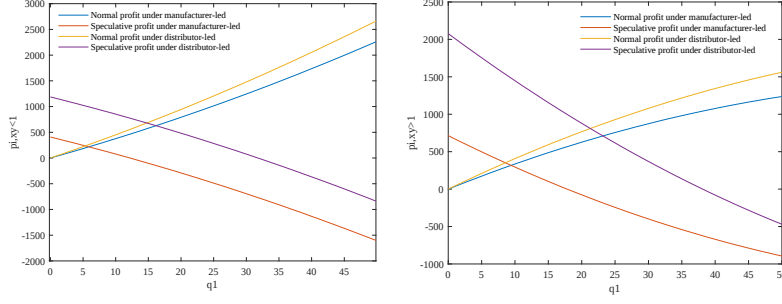


Figure 2. Comparison of normal and speculative profits under different power structures under  $\gamma x > 1$  and  $\gamma x < 1$ .

#### 4.1.2. Impact of information asymmetry on distributors' decision-making

In order to deeply analyse how information asymmetry influences distributors' pricing and decision-making behaviour, we fix the supply quantity at  $q_1 = 20$  and simulate its effects. The simulation results show that  $\gamma x$  significantly affects both the market price and distributor profitability. The wholesale price is positively correlated with the speculative preference and eventually converges to a certain limit. When  $\gamma$  is small, the wholesale price under distributor-led structure is slightly larger than that under manufacturer-led structure. As  $\gamma$  increases, the manufacturer raises the wholesale price to compensate for the risk, resulting in prices that exceed those under distributor-led structure. The effect of speculative preferences on wholesale prices is depicted in Figure 3. Additionally, the market price of distributor 1 decreases as  $\gamma$  increases, with a more rapid decline observed under manufacturer-led structure, before eventually stabilizing. Further analysis reveals that under any power structure, there exists a "hoarding trigger point", which is a critical threshold where speculative profits become dominant. Below the threshold, speculative profits are insufficient to compensate for inventory risk, leading distributors to favour maintaining regular sales. Above the threshold, speculative behaviour emerges on a large scale and becomes the distributors' optimal strategy. This finding further confirms the amplification effect of information asymmetry, where even a small degree of information distortion can trigger the systematic spread of hoarding behaviour.

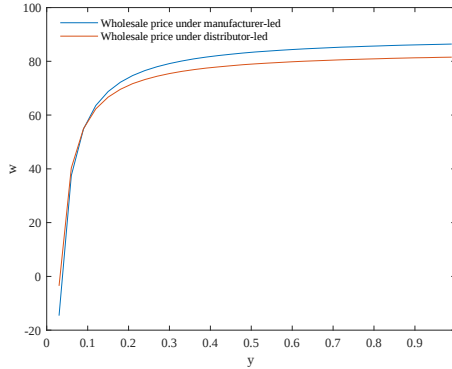


Figure 3. Impact of speculative profits  $\gamma$  on wholesale prices under the two power structures.

#### 4.1.3. Combined effect of distributor supply and information asymmetry on speculative distributor decision-making

Building upon the previous two sections, this subsection further investigates the combined effect of distributor 1's supply quantity  $q_1$  and the degree of information asymmetry  $\gamma x$  on the game equilibrium. Simulation comparisons reveal that Distributor 2's market pricing is less affected by changes in  $\gamma x$  and distributor 1's supply quantity. In contrast, distributor 1's market pricing decreases as both  $\gamma x$  and  $q_1$  increase when  $\gamma x$  is higher, reducing supply and increasing stockpiling are necessary to prevent a drop in market prices. This trend is further demonstrated in Figure 4. It is also observed that market prices are higher under the manufacturer-led structure than under the distributor-led structure. In terms of profit, when  $\gamma x$  increases and  $q_1$  decreases, speculative profit rises

significantly, while normal profits remain largely unaffected. Therefore, there exists a critical threshold, and when  $\gamma x$  exceeds this threshold and continues to increase, distributor 1's stockpile grows larger, and its speculative profit increases accordingly. In addition, speculative profits are found to be higher under the distributor-led structure than under the manufacturer-led structure. Thus, lowering  $\gamma x$  is beneficial for suppressing hoarding behaviour and preventing disruptions downstream in the supply chain. The impact on normal and speculative profits under two power structures is shown in Figure 5.

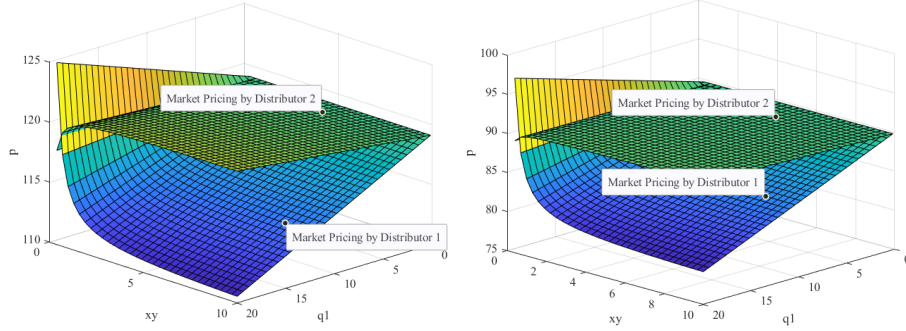


Figure 4. Impact of  $\gamma x$  and  $q_1$  on distributor prices under two power structures

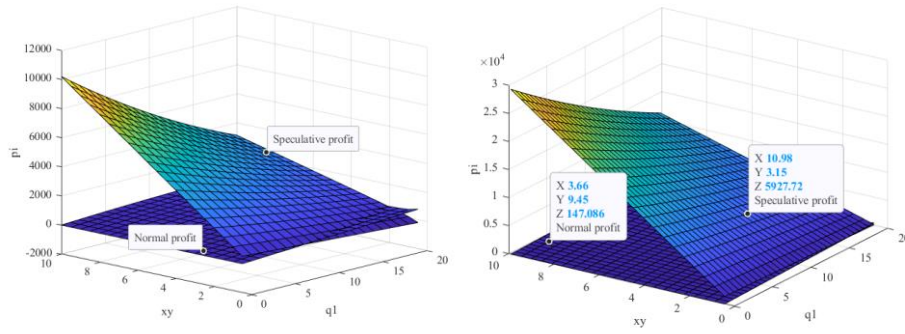


Figure 5. Impact of  $\gamma x$  and  $q_1$  on distributors' normal and speculative profits under two power structures

## 4.2. Summary

This paper investigates downstream supply chain disruptions caused by hoarding behaviour of micro-level firms and macro-level supply networks under disruption scenarios. First, under the condition of information asymmetry, the study explores how distributors in the supply chain exacerbate disruptions through speculative hoarding behaviour. Subsequently, it analyses how hoarding behaviour within the supply network under information asymmetry leads to downstream supply disruptions. The main findings are as follows: under information asymmetry, when there is stock-out risk in the external market, the wholesale price in a manufacturer-led game model is higher than that in a distributor-led model. Moreover, the impact of distributor 1's supply quantity on the wholesale price varies depending on external market conditions. When the external market experiences stock-out risk, distributor 1's pricing decreases as supply increases; the opposite holds under weak market demand. Market pricing under the manufacturer-led structure is higher than that under the distributor-led structure, distributor 2's pricing increases with the rise in supply volume. In contrast, the pattern reverses under weak external market demand. From a profitability perspective, under either power structure, it is individually optimal for distributors to reduce downstream supply and hoard goods, even though it undermines overall supply chain performance. At this point, market prices rise significantly as supply declines, and distributors can earn speculative profits that exceed normal profits. From a rational decision-maker's perspective, hoarding behaviour is triggered by the opportunity to gain speculative profits.

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