Theoretical Economics Letters, 2024, 14, 1294-1346
https://www.scirp.org/journal/tel
ISSN Online: 2162-2086
ISSN Print: 2162-2078

Cost Reduction Effect of Blockchain on the Strategies of Two Competing Manufacturers: Which Channel Alliance Is Optimal?

Xiaofei Wang[1], Zhenzhong Guan[1*], Jianbiao Ren[2]

[1]School of Economics and Management, Southwest Jiaotong University, Chengdu, China
[2]Antai College of Economics Management, Shanghai Jiaotong University, Shanghai, China
Email: *zzguan@swjtu.cn

How to cite this paper: Wang, X. F., Guan, Z. Z., & Ren, J. B. (2024). Cost Reduction Effect of Blockchain on the Strategies of Two Competing Manufacturers: Which Channel Alliance Is Optimal? *Theoretical Economics Letters, 14,* 1294-1346.
https://doi.org/10.4236/tel.2024.143065

Received: May 6, 2024
Accepted: June 25, 2024
Published: June 28, 2024

Abstract

To expand their market share, enter the market faster, and gain more sales opportunities, alternative manufacturers often choose to form alliances with incumbent supply chain companies. This paper considers a supply chain game structure composed of one incumbent manufacturer, one distributor, and one alternative manufacturer. It constructs a single-stage game model where the incumbent manufacturer sells products through two channels (direct sales and distribution). The study investigates whether the incumbent manufacturer deploys blockchain and whether the alternative manufacturer chooses to form an alliance. The research findings indicate that the incumbent manufacturer's choice to deploy a blockchain mode is closely related to the dominant region in terms of cost reduction in blockchain deployment and the intensity of product price competition. Under the deployment of blockchain, choosing direct sales channels for product distribution is always the optimal choice for the incumbent manufacturer. Furthermore, in terms of overall supply chain profit, a direct sales channel alliance is more effective than a distribution channel alliance. Interestingly, the threshold curves for the alliance strategy's dominance in overall supply chain profit and the alternative manufacturer's choice between direct sales channel or distribution channel alliance both exhibit an "L"-shaped trend. Additionally, we extend the model from a dynamic game perspective and employ the dynamic evolutionary game method to determine the evolutionarily stable strategy threshold range for the alternative manufacturer's choice of alliance strategy (direct sales or distribution) and the incumbent manufacturer's choice of blockchain deployment strategy.

Keywords

Blockchain, Supply Chain Alliance Decision, Channel Selection,

Price Competition Intensity

1. Introduction

Existing manufacturers have a leading position in the market and a high market share, and enjoy a certain market advantage. Apple Inc. is a world-renowned technology company that mainly produces and sells electronic products, such as iPhone, iPad and Mac computers. It occupies a significant share of the market through its unique design, high-quality products and strong brand influence. Alternative manufacturers are other manufacturers in the competitive market that try to replace incumbent manufacturers by offering similar but more competitive products. For example, Samsung, Xiaomi and others also produce and sell a variety of electronic products, including smartphones and tablets, and are powerful competitors of Apple Inc. Alternative manufacturers usually have a small market share and relatively low brand awareness, challenging the position of incumbent manufacturers with products of lower prices and comparable performance. In this context, dealing with the market competition of alternative manufacturers is an urgent problem for the existing manufacturers.

In addition, both existing manufacturers and alternative manufacturers want to gain a competitive advantage through innovation. Manufacturers strive to introduce new technologies to improve productivity, etc., to meet consumer demand and maintain market leadership. Technological innovation has provided a cornerstone for the continuous progress and innovation of manufacturers. The digital economy continues to develop, and digital technologies led by blockchain and artificial intelligence are booming. Enterprises are applying blockchain technology to improve supply chain transparency and reduce costs to enhance competitiveness. Huawei Cloud blockchain service, for example, is committed to its own technology to enable enterprise innovation growth, enterprise on the Huawei Cloud blockchain service can quickly build a set based on the enterprise's own business high security, high reliability, and high performance of enterprise-class blockchain system, at the same time, combined with the characteristics of cloud service visualization of data management characteristics, greatly improve the efficiency of the user use blockchain, effectively reduce the initial cost and cost. The focus of this paper is on the competition between two manufacturers producing alternative products in the context of blockchain. However, most alternative manufacturers may face disadvantages such as resource restrictions and insignificant market advantages, and are unable to invest enough capital and technology to introduce blockchain technology. If alternative manufacturers already have other competitive advantages (such as low-price strategies, innovative products, etc.), they may be more inclined to invest resources into these aspects rather than introduce blockchain technology. Moreover, the introduction of blockchain technology requires appropriate technical teams and infrastructure support, which may be a barrier for some smaller alternative manufacturers. Based on this, this paper states that incumbent manufacturers with a larger market share deploy blockchain technology, while alternative manufacturers with a smaller market share do not deploy blockchain technology.

In addition to deploying blockchain for brand building to achieve cost reduction and efficiency increase, enterprises are also expanding sales channels to increase product sales. Moreover, the incumbent manufacturers and alternative manufacturers will compete for limited sales channel resources (such as cooperation with distributors, online sales platforms, etc.), in order to better bring their products to market and obtain more sales opportunities. For example, Huawei mobile phone brand dealers directly sell products to consumers, which is called the direct channel model, and also sell products to distributors through wholesale products, which is called the distribution channel model. With the booming development of blockchain technology and manufacturer channel sales model, one of the key issues of this paper is the optimal channel selection of manufacturers under the background of the introduction of blockchain and price competition game. The practical examples listed above show that blockchain can reduce enterprise-related costs (such as enterprise initial costs, use costs, etc.). Blockchain can provide real-time transaction records and supply chain traceability, reduce logistics costs, reduce inventory and improve transportation efficiency. Therefore, this paper uses the game model theory to discuss the impact of the cost reduction degree of, supply chain deployment blockchain technology on the sales channel of enterprise decision-making products and whether deploying blockchain decisions, has important management and practical significance.

Governments are also actively pushing forward to support the deployment of blockchain technologies. The 13th Five-Year National Informatization Plan issued by the State Council of China has highlighted blockchain, big data, artificial intelligence, and other emerging technologies as key areas for national development. Furthermore, local governments across China, particularly in coastal regions, have established specialized blockchain research institutes. Currently, governments in cities such as Shenzhen, Hangzhou, and Guangzhou are proactively creating blockchain development zones and implementing tailored support policies to foster the growth of this industry. Central Europe has emerged as a global leader in shaping blockchain industrial policies. This trend can be attributed to the proactive initiatives taken by the European Union, particularly evident in the establishment of the European Blockchain Observation Forum in February 2018. This forum is dedicated to policy formulation, fostering collaboration between industry, academia, and research institutions, and building cross-border Blockchain as a Service (BaaS) infrastructure, among other responsibilities. Notably, the EU has allocated 5 million euros from the Horizon 2020 fund specifically for blockchain research and development projects. In the Middle East, Dubai stands out as a frontrunner in blockchain adoption and innovation. The city has taken a pioneering role in exploring the practical applications of blockchain technology, with strong support from both the government and private enterprises. This proactive approach has positioned Dubai as a leading hub for blockchain development in the region, setting an example for other Middle Eastern countries to follow. Apart from governmental endorsement and widespread integration of blockchain technology by businesses, academia has also been actively engaged in the discourse surrounding this emerging technology. This phenomenon can be attributed to the increasing recognition of blockchain's transformative potential across various sectors. Academic institutions are keen to explore the innovative applications, implications, and challenges posed by blockchain technology. As a result, researchers, scholars, and students are actively contributing to the advancement of blockchain knowledge and its practical implementations. The collaborative efforts between academia, industry, and government play a crucial role in driving the growth and evolution of blockchain technology ecosystem.

The academic community has extensively studied issues related to blockchain technology in addressing supply chain risks, supply chain sales channel selection, product traceability, and other related topics. Nevertheless, there has been a noticeable oversight regarding the cost considerations linked to the implementation of blockchain technology and its repercussions on market dynamics. This research paper delves into the effects of the diminishing cost barriers to entry for adopting blockchain technology on pricing strategies and delves further into the strategic implications for supply chain management within a competitive market landscape. By analyzing the evolving cost structures and their implications for market prices, this study aims to shed light on the strategic decisions that firms must make in response to the changing cost dynamics associated with blockchain adoption. Additionally, the paper seeks to offer insights into how companies can leverage blockchain technology to optimize their supply chain operations and gain a competitive edge in the market. Building upon this foundation, our objective is to tackle the following two crucial research inquiries:

1) In the scenario where a manufacturer is deciding between deploying blockchain technology and not deploying it, which sales channel, direct sales or distribution channel, should be chosen for product sales? And, when manufacturer deploys blockchain technology, how does the reduction in product unit cost after deploying blockchain technology affect the pricing strategies of the two competing manufacturers?

2) Is forming an alliance between an incumbent manufacturer and an alternative manufacturer beneficial for increasing overall supply chain profits? When is the best time to form such an alliance?

In response to these challenges, this paper assumes that two manufacturers selling similar products compete in the market. Incumbent manufacturers can sell their products to consumers through two channels: direct sales and distribution. In order to enhance product competitiveness and promote enterprise cost reduction and efficiency, incumbent manufacturers also decide whether to deploy blockchain. At the same time, alternative manufacturers sell products directly to consumers and compete with incumbent manufacturers. In order to maximize benefits and promote product sales, alternative manufacturers also choose to form alliances with companies in the existing supply chain. The key findings of this study are as follows:

1) In cases where the incumbent manufacturer opts against implementing blockchain technology, the distribution channel associated with the incumbent manufacturer yields greater benefits in terms of product sales compared to the direct sales channel. Conversely, the direct sales channel proves to be the optimal choice.

2) The deployment of blockchain is not necessarily for the optimal choice for the supply chain, there are cost threshold conditions to make the deployment of blockchain is optimal. In the direct sales domain, the blockchain cost reduction threshold crucial for fostering a mutually beneficial relationship between the incumbent manufacturer and the alternative manufacturer is intricately linked to the competitive intensity within the product market, while in the distribution channel, the cost reduction threshold for the deployment of blockchain is a fixed value.

3) Analysis of alliance decision: we examine the critical threshold conditions under which channel alliance emerges as the superior option, and the advantages of alliance decision over non-alliance decision in the context of blockchain implementation. Under the condition that the cost reduction threshold of deploying blockchain is certain, the greater the competition intensity, the better the alliance effect. But as consumer privacy concerns have grown, so have the advantages of alliances.

4) We compare the results of static games and dynamic games. Moreover, we find that the static game concludes that there are threshold conditions for blockchain cost reduction that make the direct sales channel alliance or distribution channel alliance optimal for alternative manufacturers. Based on the analysis of dynamic game theory, it is determined that over the long term, the incumbent manufacturer and the alternative manufacturer will adopt a stable strategy (utilizing blockchain, forming distribution channel alliances) only if the proportion of the total cost attributed to blockchain is below 1/2.

This paper's contribution lies in the integration of three key factors: the extent of cost reduction associated with blockchain deployment, the level of price competition intensity, and the degree of consumer privacy concerns. By analyzing the interplay of these factors, the study explores their influence on the strategic decision-making of two manufacturers. Furthermore, by combining static and dynamic game theory, it derives the strategic behavior choices of the two manufacturers under short-term and long-term decision-making scenarios. This in-depth analysis seeks to offer a deeper understanding of how the interaction among these factors shapes the decision-making processes and competitive strategies of manufacturers within the framework of blockchain adoption, price competition, and consumer privacy considerations. By delving into these dynamics, the study aims to shed light on the strategic behaviors adopted by manufacturers in response to the evolving landscape of technology, market competition, and consumer preferences. The study sheds light on the strategic implications for manufacturers in both the immediate and long-term horizons, offering valuable guidance for strategic planning and decision-making in the evolving business landscape.

The structure of this paper is as follows: The second section is the literature review of this paper, from the supply chain blockchain and supply chain competition and cooperation in two aspects of literature review. The third section is about the model hypothesis and equilibrium solution. The most equilibrium solution of the model in four cases is solved respectively. The fourth section is the model comparison analysis, we compare the product price and product sales under the direct selling channel and the distribution channel. The profit decisions in a blockchain deployment and non-deployment mode were also compared. Section 5 studies the alliance between alternative manufacturers and incumbent manufacturers and retailers respectively. Section 6 is the extension part of this paper. We extend the model from the dynamic game point of view and compare it with the static game in this paper. Finally, Section 7 provides a summary of the paper's conclusions, and managerial implications, and outlines areas for future research.

2. Literature Review

2.1. Blockchain in Supply Chain

Within the realm of blockchain technology, the application of game theory among participants in the supply chain has emerged as a prominent subject of discussion within the academic domain of supply chain management. This growing interest underscores a heightened focus on investigating the strategic dynamics and decision-making mechanisms among stakeholders operating within a blockchain-enabled supply chain ecosystem. Scholars are actively engaged in deciphering the ways in which blockchain technology can elevate levels of transparency, trust, and operational efficiency within supply chain processes, while also exploring the potential for leveraging game theory principles to optimize decision-making processes and foster collaboration among the various actors involved in the supply chain network. By delving into these intersections between blockchain, game theory, and supply chain management, researchers aim to shed light on innovative strategies that can revolutionize the operational landscape and cultivate sustainable competitive advantages for organizations in the contemporary business environment. This intersection of blockchain and game theory opens up new avenues for innovative research and practical applications in supply chain management. Blockchain traceability features are also being used to study risk science in supply chains, Cui et al. (2023) believe that blockchain technology plays an indispensable role in alleviating the double moral hazard in the supply chain, and at this time, suppliers will also improve product quality. Dong et al. (2023) believe that leveraging blockchain traceability can increase revenue for each supply chain member. From the perspective of blockchain cost, Tao et al. (2022) considers the price and quality decisions of the platform supply chain under the role of blockchain, and Tao et al. (2022) believe that the degree to which blockchain reduces production costs determines the pricing and product quality decisions of suppliers. In addition, in addition to the study of blockchain + supply chain channels, there are some scholars who use the traceability characteristics of blockchain to study the blockchain in combating counterfeit goods (Pun et al., 2021; Shen et al., 2022). Shen et al. (2022) believe that blockchain technology increases the profits of brand manufacturers and social welfare. Li et al. (2021) delve into the intricate relationship between the integration of blockchain technology and the strategic selection of distribution channels in the battle against counterfeit goods. Li et al. (2021) posit that in scenarios where the prevalence of fraudulent counterfeits is notably high, post the implementation of blockchain, manufacturers are advised to opt for direct sales channels as their primary distribution channel. While blockchain presents a viable solution to enhance supply chain transparency, it also raises concerns regarding consumer privacy, as highlighted in studies by (Pun et al., 2021; Shen et al., 2022). This study synthesizes existing literature on consumer privacy apprehensions post-blockchain adoption, particularly focusing on the interplay among "consumer privacy concerns, blockchain cost reduction levels, and product price competition" in shaping the strategic decisions of two manufacturers. By exploring these dynamics, the paper aims to offer insights into the nuanced complexities of balancing transparency, privacy, and competitiveness in the context of blockchain-enabled supply chains.

2.2. Competition and Cooperation in Supply Chain

In addition, some scholars pay attention to the competition and cooperation relationship between enterprises. Bakshi and Kleindorfer (2009) considered a supply chain with two participants and analyzed the synergistic competitive advantage in the context of managing supply chain security. Tan and Liu (2018) based on the game problem of price competition between three supply chains, ten different models of decision-making are established, and the reasons for low-price competition between the two supply chains are quantitatively analyzed. It is found that when the products provided by the two supply chains are replaceable. Luo et al. (2016) analyzed the role of collaborative competition between two manufacturers in low-carbon production by using the game model and found that cooperation would bring more profits and less total carbon emissions. The centralized decision-making of the alliance between enterprises in the supply chain can enhance the pricing power of enterprises and realize the win-win situation through the coordination mechanism of profit distribution. By developing a game theory model, Mantovani and Ruiz-Aliseda (2016) found that enterprises can improve the quality of innovation ecosystem through cooperation. Yang et al. (2018) used the concept of concurrence and Cournot competition model to analyze the optimal distribution strategy of suppliers with limited supply capacity. Wu et al. (2021) examined a scenario involving a common supplier and two competing manufacturers, where the supplier acts as a Stackelberg leader. The supplier strategically offers cooperation proposals to one or both manufacturers, investigating the impacts of spillover rates, research and development efficiency, and competition levels on the equilibrium outcomes. Niu et al. (2022) examined the competition between overseas and local suppliers, taking into account the trade-off between blockchain costs and market potential. The research revealed that in cases where the costs associated with adopting blockchain technology surpass a certain threshold for electronic retailers, they are inclined to establish higher pricing structures for both local and overseas suppliers. This underscores the critical role of conducting cost-benefit analyses in the decision-making processes within the electronic retail industry, especially concerning the integration of blockchain technology and its implications on supplier pricing strategies. While existing literature predominantly examines the downstream competitive decisions within the supply chain, this study shifts its focus to the upstream competitive decisions made by manufacturers in the supply chain. More specifically, the competitive decision-making process entails evaluating product price competition between two manufacturers, determining whether the incumbent manufacturer should implement blockchain technology, and deciding whether the alternative manufacturer should opt for an alliance strategy. This study aims to provide a comprehensive understanding of the strategic choices and implications associated with blockchain adoption in the context of supplier relationships in the electronic retail sector.

Based on the findings of the literature review (see **Table 1**), it has been observed that there is a limited number of scholars addressing the simultaneous consideration of the alliance strategy within competitive supply chains and the channel selection strategy of the incumbent manufacturer in the context of blockchain technology implementation. In our research underscores the need for further exploration into the strategic interactions between alliance formation and channel selection decisions in the supply chain dynamics influenced by blockchain technology adoption. By delving deeper into this intersection, we can gain valuable insights into the complex decision-making processes involved in optimizing supply chain strategies amidst technological advancements such as blockchain. And few scholars used static game and dynamic game to conduct comparative research on such issues. The innovation points of this paper are as follows:

First, integrate the three factors of "the degree of cost reduction in the deployment of blockchain, the intensity of price competition, and the degree of consumer privacy concern", and explore the impact of these three factors on the strategic behavior choice of the two manufacturers. Second, by combining static game and dynamic game, we can get the results of two manufacturers' strategic behavior selection under short-term decision and long-term decision. To this end, this study explores the changes in the strategies of incumbent manufacturers (channel choice, decision on whether to deploy blockchain) and alliance choices of alternative manufacturers (alliance strategy or not) under the influence of the degree of blockchain cost reduction, the intensity of product price competition, and the degree of consumer privacy concern.

3. Model Description, Assumptions and Equilibrium

This study sets up a competition in the market between two manufacturers selling

Table 1. Literature comparison.

Paper	Blockchain	Consumer privacy concerns	Compete	Collaboration (alliance)	Static game	Dynamic game
Pun et al. (2021)	√	√	×	×	√	×
Shen et al. (2022)	√	√	×	×	√	×
Gong et al. (2023)	√	×	×	×	√	×
Wu and Yu (2022)	√	×	×	×	√	×
Li et al. (2021)	√	×	×	×	√	×
Cui et al. (2023)	√	×	√	×	√	×
Tao et al. (2022)	√	×	√	×	√	×
Luo et al. (2016)	×	×	√	√	√	×
Mantovani and Ruiz-Aliseda (2016)	×	×	√	√	√	×
Yang et al. (2018)	×	×	√	√	√	×
Our paper	√	√	√	√	√	√

similar products. The incumbent manufacturer can sell products to consumers through two channels: direct sales channel and distribution channel. Based on the above description, there are a total of four modes: direct sales channel without deploying blockchain (DN), direct sales channel deploying blockchain (DB), distribution channel without deploying blockchain (RN), and distribution channel deploying blockchain (RB). Furthermore, the superscript $\Psi = \{M_1, M_2, R\}$ is used to respectively represent the incumbent manufacturer, the alternative manufacturer, and the distributor. **Figure 1** shows the model logic for this article.

In order to provide a clear and logical description of the model assumptions, we elaborate on the model assumptions from four aspects: demand function, blockchain deployment, cost structure, and model decision sequence.

Demand function: This article employs the Bertrand model, where γ represents the intensity of price competition between incumbent manufacturers and alternative manufacturers (Raju et al., 1995; Shang et al., 2016; Tsunoda & Zennyo, 2021). The quantity demanded for products from the incumbent manufacturers is denoted as $q_1 = a - p_1 + \gamma(p_2 - p_1)$, while the quantity demanded for products from alternative manufacturers is denoted as $q_2 = a - p_2 + \gamma(p_1 - p_2)$. The model following the setup in reference (Cui et al. 2023), this article normalizes the market capacity to 1, such that the product demand quantities are represented as $q_1 = 1 - p_1 + \gamma(p_2 - p_1)$ and $q_2 = 1 - p_2 + \gamma(p_1 - p_2)$.

Deploying blockchain: With reference to literature (De Giovanni, 2020; Shen et al., 2022), enterprises typically incur a fixed cost when deploying blockchain technology, denoted as F in this study. To simplify the model, the base model does not consider the fixed cost of deploying blockchain, but the extension includes the consideration of this fixed cost to validate the robustness of the model and further enhance its resilience. In the extension, drawing from literature (Pun et al., 2021; Shen et al., 2022), the cost of consumer privacy concerns related to blockchain technology is denoted as T. Additionally, in the context of product sales through distribution channels, this study sets λ as the proportion borne by the incumbent manufacturer for the total cost of using blockchain and privacy concerns, while $1-\lambda$ represents the remaining proportion to be shared by the distributor.

Cost Structure: Assuming that blockchain technology can reduce the production cost per unit δ (Tao et al., 2022). For the sake of exposition and analysis, this study sets the production cost of products with blockchain technology to zero, thus setting the production cost of products without blockchain technology to δ. It is worth noting that the key issue addressed in this study is the joint impact of the decrease in costs of incumbent manufacturers deploying blockchain, the intensity of price competition, and consumer concerns about blockchain privacy on the choice of supply chain channels and alliance strategies. Therefore, to simplify the model, this study assumes that the unit costs of incumbent manufacturers, alternative manufacturers, and distribution channel distributors are equal.

Model Decision Sequence: According to the literature (Cui et al., 2023; Gong et al., 2023), it is assumed that the game is completed within one period. In the competition of direct sales channels, the decision sequence is as follows: first, the incumbent manufacturer decides whether to deploy blockchain, then the incumbent manufacturer decides the selling price p_1 of the product, and finally the alternative manufacturer decides the competitive selling price p_2 of the product. In the competition of distribution channels, the decision sequence is as follows: first, the incumbent manufacturer decides whether to deploy blockchain, then the incumbent manufacturer decides the wholesale price \$w\$ of the product, next the distributor decides the selling price p_1 of the product, and finally the alternative manufacturer decides the selling price p_2 of its product.

The summary description of all symbols in this paper is shown in **Table 2**. **Figure 1** is the model framework design of this paper.

Table 2. Detailed description table of the symbols.

Symbol	Description
Sign	
$i=\{D,R\}$	Logos of direct sales channels and distribution channels
$j=\{B,N\}$	Flags for deploying a blockchain and not deploying a blockchain
Parameter	
Δc	The unit cost that decreases after the blockchain is deployed
F	Fixed costs for deploying blockchain technology
λ	The manufacturer is responsible for the proportion of the total cost of using blockchain technology
γ	Intensity of price competition
T	The cost of consumer privacy concerns about deploying blockchain technology
Decision variables	
w	The wholesale price determined by the manufacturer
p_1	The selling price determined by the incumbent manufacturer/distributor
p_2	The selling price determined by the alternative manufacturer
π_{Ψ}^{ij}	The profit of game participant Ψ in model ij $\Psi=\{M_1,M_2,R\}$

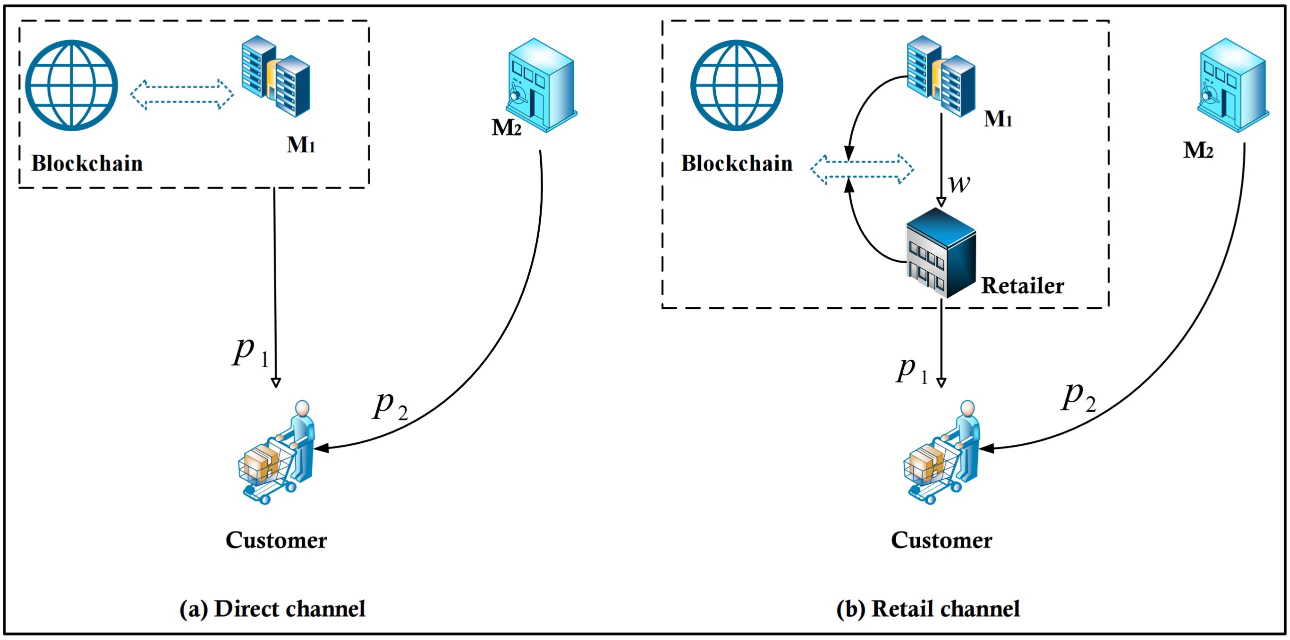


Figure 1. The model logic.

3.1. Direct Channels Do Not Deploy Blockchain (DN)

In the Direct-to-Consumer (DN) mode, the incumbent manufacturer opts to directly sell products to end consumers. Initially, the incumbent manufacturer decides against implementing blockchain technology. Following this decision, the incumbent manufacturer sets the selling price for the product, after which the alternative manufacturer determines its selling price. Subsequently, both the incumbent manufacturer and the alternative manufacturer engage in strategic game decisions aimed at maximizing their individual profits. The profit functions of the incumbent manufacturer (M_1) and the alternative manufacturer (M_2) can be defined as follows:

$$\pi_{M_1}^{DN}\left(p_1\right)=\left(p_1-\Delta c\right)q_1 . \tag{1}$$

$$\pi_{M_2}^{DN}\left(p_2\right)=\left(p_2-\Delta c\right)q_2 \tag{2}$$

The optimal equilibrium solution under DN mode is obtained by backward induction. The calculation process is shown in **Appendix**.

Lemma 1. In Model DN, the optimal equilibrium solution is as follows:

$$p_1^{DN*}=\frac{2\Delta c\gamma^2+5\Delta c\gamma+2\Delta c+3\gamma+2}{2\left(\gamma^2+4\gamma+2\right)},$$

$$p_2^{DN*}=\frac{4\Delta c\gamma^3+\left(15\Delta c+5\right)\gamma^2+\left(14\Delta c+10\right)\gamma+4\Delta c+4}{4\left(\gamma^2+4\gamma+2\right)\left(\gamma+1\right)},$$

$$\pi_{M_1}^{DN*}=\frac{\left(\Delta c-1\right)^2\left(3\gamma+2\right)^2}{8\left(\gamma^2+4\gamma+2\right)\left(\gamma+1\right)},\quad \pi_{M_2}^{DN*}=\frac{\left(\Delta c-1\right)^2\left(5\gamma^2+10\gamma+4\right)^2}{16\left(1+\gamma\right)\left(\gamma^2+4\gamma+2\right)^2}.$$

3.2. Distribution Channels without Deploying Blockchain (RN)

In the Resale Network (RN) mode, the incumbent manufacturer opts to distribute products to wholesalers, who subsequently retail the products to end consumers. The incumbent manufacturer makes the strategic choice of not implementing blockchain technology, establishes the wholesale price of the product, and then delegates the decision-making on the selling price to the distributor within their distribution network. Following this, the alternative manufacturer determines the final selling price of the product. In this dynamic, the incumbent manufacturer, distributor, and alternative manufacturer partake in strategic game-theoretic decisions with the primary objective of maximizing their respective profits. The profit functions of the incumbent manufacturer (M_1), distributor (R), and alternative manufacturer (M_2) can be described as follows:

$$\pi_{M_1}^{RN}(w) = (w - \Delta c)q_1 \tag{3}$$

$$\pi_{R}^{RN}(p_1) = (p_1 - w - \Delta c)q_1 \tag{4}$$

$$\pi_{M_2}^{RN}(p_2) = (p_2 - \Delta c)q_2 \tag{5}$$

The optimal equilibrium solution under RN mode is obtained by backward induction. The calculation process is shown in **Appendix**.

Lemma 2. The optimal equilibrium solution is:

$$w^{RN*} = \frac{\Delta c\gamma^2 + \Delta c\gamma + 3\gamma + 2}{2(\gamma^2 + 4\gamma + 2)},\quad p_1^{RN*} = \frac{5\Delta c\gamma^2 + (11\Delta c + 9)\gamma + 4\Delta c + 6}{4(\gamma^2 + 4\gamma + 2)}$$

$$p_2^{RN*} = \frac{9\Delta c\gamma^3 + (31\Delta c + 13)\gamma^2 + (28\Delta c + 22)\gamma + 8\Delta c + 8}{8(\gamma^2 + 4\gamma + 2)(\gamma + 1)},$$

$$\pi_{M_1}^{RN*} = \frac{(\Delta c\gamma^2 + (7\Delta c - 3)\gamma + 4\Delta c - 2)^2}{16(1+\gamma)(\gamma^2 + 4\gamma + 2)},$$

$$\pi_{M_2}^{RN*} = \frac{(\Delta c\gamma^3 + (13 - 9\Delta c)\gamma^2 + (22 - 20\Delta c)\gamma - 8\Delta c + 8)^2}{64(1+\gamma)(\gamma^2 + 4\gamma + 2)^2}$$

$$\pi_{R}^{RN*} = \frac{(\Delta c\gamma^2 + (7\Delta c - 3)\gamma + 4\Delta c - 2)^2}{32(1+\gamma)(\gamma^2 + 4\gamma + 2)}$$

3.3. Direct Channels Deploy Blockchain (DB)

In the Direct-to-Consumer (DB) mode, the incumbent manufacturer elects to directly market products to end consumers, with the incumbent manufacturer taking the lead in deploying blockchain technology. The incumbent manufacturer sets the selling price of the product, after which the alternative manufacturer determines the final selling price. Subsequently, both the incumbent manufacturer and the alternative manufacturer participate in strategic decision-making processes aimed at profit maximization. The profit functions of the incumbent manufacturer (M_1) and alternative manufacturer (M_2) are defined as Equations (6) and (7) respectively:

$$\pi_{M_1}^{DB}(p_1) = p_1 q_1 \tag{6}$$

$$\pi_{M_2}^{DB}(p_2) = (p_2 - \Delta c) q_2 \tag{7}$$

The optimal equilibrium solution under DB mode is obtained by backward induction. The calculation process is shown in **Appendix**.

Lemma 3. The optimal equilibrium solution:

$$p_1^{DB*} = \frac{\gamma^2 \Delta c + \gamma \Delta c + 3\gamma + 2}{2(\gamma^2 + 4\gamma + 2)},$$

$$p_2^{DB*} = \frac{3\Delta c \gamma^3 + (11\Delta c + 5)\gamma^2 + (12\Delta c + 10)\gamma + 4\Delta c + 4}{4(\gamma^2 + 4\gamma + 2)(\gamma + 1)},$$

$$\pi_{M_1}^{DB*} = \frac{\left(2 + \gamma^2 \Delta c + (\Delta c + 3)\gamma\right)^2}{8(\gamma^2 + 4\gamma + 2)(\gamma + 1)},$$

$$\pi_{M_2}^{DB*} = \frac{\left(\Delta c \gamma^3 + (9\Delta c - 5)\gamma^2 + (12\Delta c - 10)\gamma + 4\Delta c - 4\right)^2}{16(1+\gamma)(\gamma^2 + 4\gamma + 2)^2}.$$

3.4. Distribution Channels Deploy Blockchain (RB)

In the RB mode, the incumbent manufacturer chooses to wholesale products to distributors, who then sell the products to consumers. The incumbent manufacturer makes decisions on deploying blockchain, setting wholesale prices for the products, and then the distributor decides on the selling price through their distribution channels. Finally, the alternative manufacturer makes a decision on the selling price. The incumbent manufacturer, distributor, and alternative manufacturer engage in game decisions with the goal of maximizing their own profits. The profit functions of the incumbent manufacturer (M_1), distributor (R), and alternative manufacturer (M_2) are as follows (8), (9), and (10) respectively:

$$\pi_{M_1}^{RB}(w) = w q_1 \tag{8}$$

$$\pi_{R}^{RB}(p_1) = (p_1 - w) q_1 \tag{9}$$

$$\pi_{M_2}^{RB}(p_2) = (p_2 - \Delta c) q_2 \tag{10}$$

Lemma 4. The optimal equilibrium solution:

$$w^{RB*} = \frac{\Delta c \gamma^2 + \Delta c \gamma + 3\gamma + 2}{2(\gamma^2 + 4\gamma + 2)}, \quad p_1^{RB*} = \frac{3\Delta c \gamma^2 + (3\Delta c + 9)\gamma + 6}{4(\gamma^2 + 4\gamma + 2)},$$

$$p_2^{RB*} = \frac{7\Delta c \gamma^3 + (23\Delta c + 13)\gamma^2 + (24\Delta c + 22)\gamma + 8\Delta c + 8}{8(\gamma^2 + 4\gamma + 2)(\gamma + 1)},$$

$$\pi_{M_1}^{RB*} = \frac{\left(2 + \Delta c\gamma^2 + (\Delta c + 3)\gamma\right)^2}{16(1+\gamma)\left(\gamma^2 + 4\gamma + 2\right)},$$

$$\pi_{M_2}^{RB*} = \frac{\left(\Delta c\gamma^3 + (17\Delta c - 13)\gamma^2 + (24\Delta c - 22)\gamma + 8\Delta c - 8\right)^2}{64(1+\gamma)\left(\gamma^2 + 4\gamma + 2\right)^2},$$

$$\pi_{R}^{RB*} = \frac{\left(2 + \Delta c\gamma^2 + (\Delta c + 3)\gamma\right)^2}{32(1+\gamma)\left(\gamma^2 + 4\gamma + 2\right)}.$$

4. Comparative Analysis of Models

4.1. Channel Selection for Incumbent Manufacturers-Profit Comparison (DN vs. RN and DB vs. RB)

In the face of alternative manufacturer intrusion, in order to find the optimal channel choice for incumbent manufacturers, this section makes a comparative analysis of the direct sales channel profits and distribution channel profits of incumbent manufacturers under the circumstances of deploying blockchain and not deploying blockchain.

Proposition 1. When $0 < \Delta c < c^*$, there is $\pi_{M_1}^{DN*} > \pi_{M_1}^{RN*}$; when $\Delta c > c^*$, there is $\pi_{M_1}^{DN*} < \pi_{M_1}^{RN*}$.

Proof: The proof process is more complex, and the specific details are shown in **Appendix**.

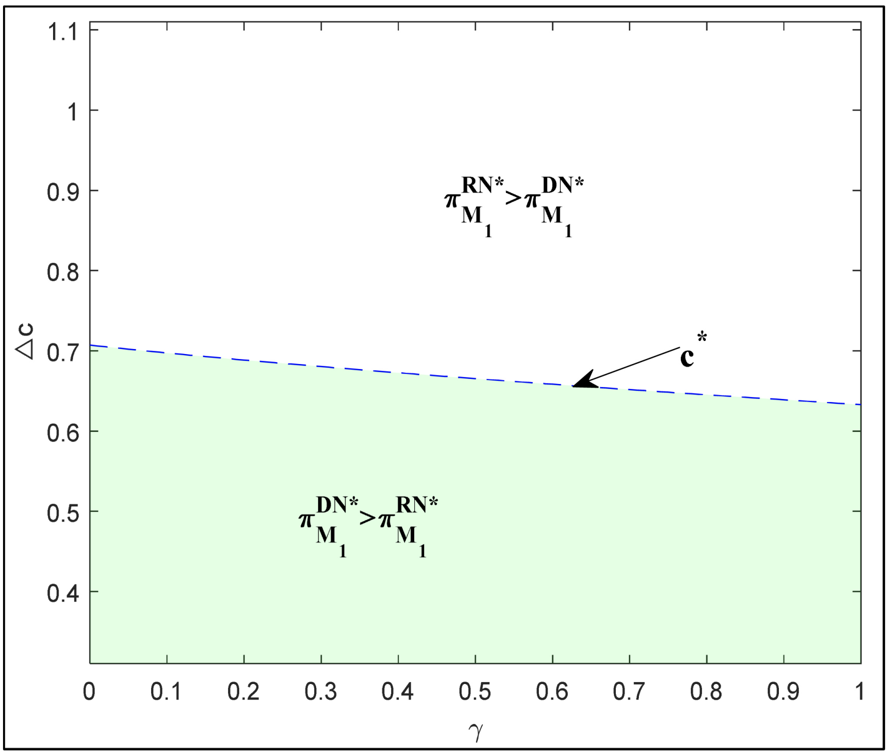


Figure 2. $\pi_{M_1}^{RN*}$ vs. $\pi_{M_1}^{DN*}$.

Proposition 1 demonstrates the intricate relationship between the incumbent manufacturer's channel choice and the cost reduction threshold associated with blockchain deployment in the absence of blockchain technology. **Figure 2** illustrates the evolving trend of threshold variations in channel selection for incumbent manufacturers without blockchain implementation. **Figure 2** highlights that as the level of competition in product pricing intensifies, the threshold for channel selection tends to decrease. Notably, a direct correlation is observed between the heightened competition intensity and the expanded region where the incumbent manufacturer's profits within the distribution channel surpass those of the direct sales channel.

In summary, Proposition 1 underscores that in scenarios where blockchain technology is not utilized, incumbent manufacturers are advised to opt for distribution channels for product sales under the combined influence of elevated blockchain cost reduction thresholds and heightened price competition. This strategic decision-making process, aimed at profit maximization, underscores the critical importance of considering both cost dynamics and competitive market conditions in channel selection strategies within the distribution ecosystem.

Proposition 2. $\pi_{M_1}^{DB*} > \pi_{M_1}^{RB*}$.

Proof: $\pi_{M_1}^{DB*} - \pi_{M_1}^{RB*} = \dfrac{\left(2+\Delta c\gamma^2+\left(\Delta c+3\right)\gamma\right)^2}{16\left(\gamma^2+4\gamma+2\right)\left(1+\gamma\right)} > 0$.

The conclusion of Proposition 2 is similar to that of literature Li et al. (2021), but the results of literature (Li et al., 2021) that direct sales channel is superior to retail channel exist threshold conditions, and under the assumptions of the model in this paper, the research finds that direct sales channel is always the best choice for incumbent manufacturers when deploying blockchain.

4.2. Comparative Price Analysis

In this section, the equilibrium prices of incumbent and alternative manufacturers are compared and analyzed, and some interesting conclusions are drawn.

First, the sales price of the existing manufacturer is compared with that of the alternative manufacturer under the direct sales channel (D) and distribution channel (R) respectively, and the following results are obtained:

Proposition 3. $0 < \Delta c < 1$, $p_1^{DN*} > p_2^{DN*}$; $0 < \Delta c < \Delta c_1$, $p_1^{DB*} > p_2^{DB*}$.

Proof: The proof process is more complex, and the specific details are shown in **Appendix**.

Proposition 3 elucidates the distinct conditions governing the blockchain cost reduction threshold for the sales price of the incumbent manufacturer compared to that of competitive products in both scenarios: with and without blockchain deployment within the direct sales channel. In the absence of blockchain technology, the blockchain cost reduction threshold condition remains constant, while the introduction of blockchain (δ) is intricately linked to the level of product price competition.

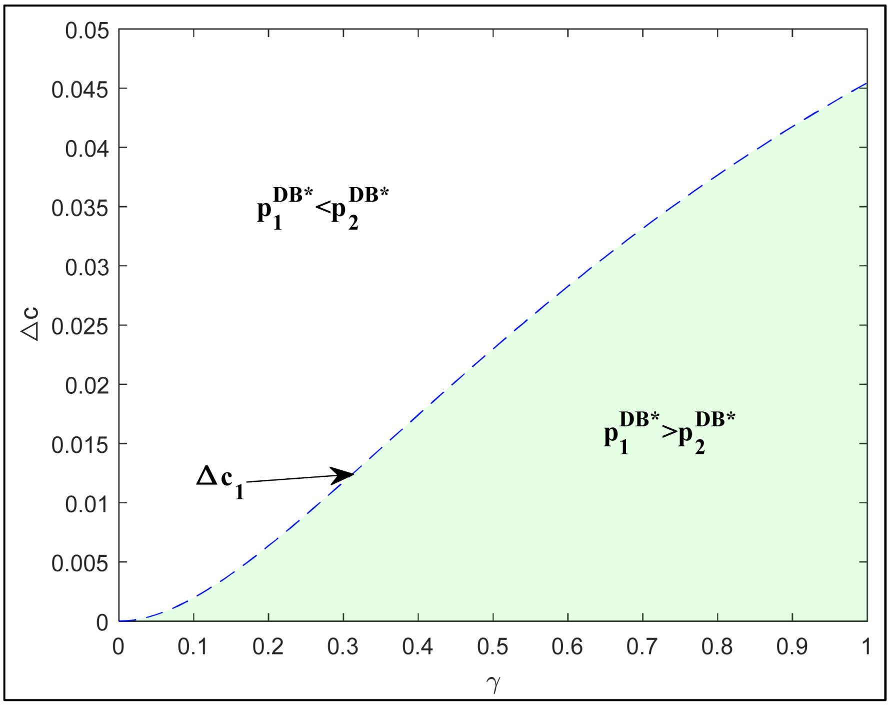


Figure 3. p_1^{DB*} vs. p_2^{DB*}.

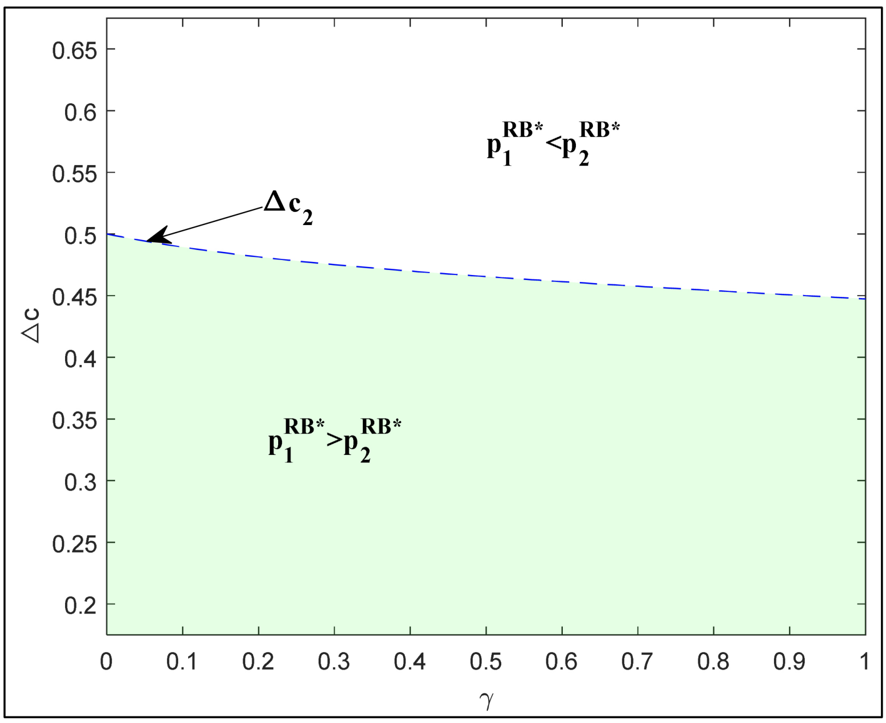


Figure 4. p_1^{RB*} vs. p_2^{RB*}.

As depicted in **Figure 3**, a direct correlation is observed between the intensity of price competition and the magnitude of the blockchain cost reduction threshold. Specifically, heightened competition in product pricing leads to an increase in the threshold required for blockchain implementation. This dynamic relationship underscores the importance of considering market competitiveness when evaluating the cost-effectiveness of blockchain deployment within the context of direct sales channels.

Proposition 4. $p_1^{RN*} > p_2^{RN*}$. $\Delta c > \Delta c_2$, there are $p_1^{RB*} < p_2^{RB*}$; when $0 < \Delta c < \Delta c_2$, there are $p_1^{RB*} > p_2^{RB*}$.

Proof. The proof process is more complex, and the specific details are shown in **Appendix**.

Proposition 4 demonstrates that within the distribution channel, the relationship between product selling prices shifts based on the deployment status of blockchain technology. Specifically, in the absence of blockchain deployment, the selling price of the incumbent product consistently exceeds that of the alternative manufacturer. Conversely, with blockchain implementation, the selling price of the incumbent product surpasses that of the competing product in correlation with the cost reduction threshold (δ_2).

In Figure 4, it is evident that the intensity of price competition inversely affects the threshold for cost reduction associated with blockchain deployment. A key finding is the decrease in the threshold magnitude as price competition intensifies, indicating a more cost-effective scenario for blockchain integration. This observation contrasts with the threshold trends identified in Proposition 3, highlighting the nuanced impact of market dynamics on the cost implications of blockchain adoption within distribution channels.

The reason behind this phenomenon lies in the unique dynamics of competition and pricing strategies in the distribution channel. When blockchain technology is not utilized, the incumbent manufacturer may rely on factors such as brand reputation, customer loyalty, or product differentiation to maintain higher sales prices compared to alternative manufacturers. This can create a pricing hierarchy where the incumbent product commands a premium over substitutes due to perceived value or market positioning. However, when blockchain is introduced, the cost reduction threshold becomes a critical factor in determining the competitive pricing landscape. In a highly price-competitive environment, where margins are slim and customers are sensitive to price changes, the incumbent manufacturer may need to leverage blockchain technology to reduce costs and maintain competitiveness. The lower the cost reduction threshold, the more likely it is for the incumbent manufacturer to adjust pricing strategies and align with market demands, potentially leading to a scenario where the sales price of the incumbent product remains higher than that of competing products.

This shift in pricing dynamics highlights the strategic importance of cost optimization and competitive positioning in the distribution channel. By understanding the interplay between blockchain deployment, cost reduction thresholds, and price competition, manufacturers can make informed decisions to enhance their market position, improve profitability, and navigate the evolving landscape of the distribution channel effectively.

Then, the sales prices of products with and without blockchain deployment under the two channels are compared respectively. The following proposition is obtained:

Proposition 5. $p_1^{DB*} < p_1^{DN*}, p_2^{DB*} < p_2^{DN*}$, $p_1^{RB*} < p_1^{RN*}, p_2^{RB*} < p_2^{RN*}$.

Proof. The proof process is more complex, and the specific details are shown in **Appendix**.

The consistent price disparity between products with and without blockchain deployment in both sales channels can be attributed to the cost efficiencies and transparency benefits that blockchain technology brings to the supply chain and sales processes. Products integrated with blockchain often benefit from reduced operational costs, enhanced traceability, and increased trust among consumers, enabling manufacturers to offer them at a lower price point.

Finally, the price of products of existing manufacturers and alternative manufacturers are compared, and the price of products in which channel is higher.

Proposition 6. For incumbent manufacturers, whether blockchain is deployed or not, there is always $p_1^R > p_1^D$, and in the context of distribution channels versus direct channels, it is consistently observed that product prices tend to be higher in the former. Furthermore, when the incumbent manufacturer opts for the distribution channel for product sales, a scenario arises where the alternative manufacturer seizes the opportunity to enter the market. This incursion results in an escalation of prices for the alternative manufacturer's own products.

Proof. The proof process is more complex, and the specific details are shown in **Appendix**.

Regarding the pricing discrepancy between distribution and direct sales channels for incumbent manufacturers, this can be attributed to the different cost structures and market positioning associated with each channel. Distribution channels typically involve additional intermediaries, logistics costs, and markups, leading to higher prices compared to direct sales where manufacturers interact directly with consumers. When the incumbent manufacturer transitions to the distribution channel, it creates an opportunity for alternative manufacturers to enter the market due to potential gaps or shifts in consumer preferences. This competitive intrusion prompts an increase in the alternative manufacturer's product pricing as they aim to capitalize on the incumbent's channel choice and potentially capture market share.

The reason behind this phenomenon (Proposition 5 and Proposition 6) can be attributed to several factors within the competitive landscape of the manufacturing industry.

1) Distribution channel value: the distribution channel often adds value to products through services such as warehousing, transportation, and marketing. This added value allows manufacturers to command higher prices in the distribution channel compared to direct sales.

2) Competition and intrusion: when incumbent manufacturers choose the distribution channel, alternative manufacturers may view this as an opportunity

for competitive intrusion. By raising their own product prices, alternative manufacturers aim to capitalize on the incumbent's decision and potentially gain market share or increase profitability.

3) Supply chain efficiency: distribution channels often offer a more efficient supply chain network, leading to cost savings for manufacturers. These savings can be reflected in pricing strategies, allowing manufacturers to maintain higher prices in the distribution channel.

4) Channel conflict management: incumbent manufacturers may face challenges in managing channel conflicts when selling directly to customers. By opting for the distribution channel, they can mitigate these conflicts and maintain better relationships with distributors and retailers, which can influence pricing dynamics.

Overall, the interaction of these factors contributes to the observed pricing differences between distribution and direct sales channels for incumbent and alternative manufacturers.

4.3. Comparative Analysis of Product Sales

In this section, a comparative analysis of product sales volume decisions of incumbent manufacturers and alternative manufacturers is made, and some interesting conclusions are drawn.

Proposition 7. $\Delta c > 1$, $q_1^{DN*} > q_2^{DN*}$. $\Delta c > \Delta c_3$, $q_1^{DB*} > q_2^{DB*}$. $0 < \Delta c < \Delta c_3$, $q_1^{DB*} < q_2^{DB*}$.

Proposition 8. When blockchain technology is not utilized, the incumbent manufacturer typically experiences lower product sales compared to the alternative manufacturer. However, upon the deployment of blockchain technology, a shift in the competitive landscape is observed, Only when $\Delta c > \Delta c_4$, the existing manufacturer's product sales are higher than the replacement manufacturer's product sales.

Proposition 7 and Proposition 8 indicate that the change trend of the threshold value of product sales comparison is the same as that of product price comparison, except that the size of the threshold area is opposite (as shown in Figure 5 and Figure 6). This fits with a common economic theory: higher prices lead to lower product sales. Comparing Figure 5 and Figure 6 with Figure 3 and Figure 4, it can be concluded that: higher prices lead to lower product sales. For example, as shown in Figure 5, when $0 < \Delta c < \Delta c_3$, there is $q_1^{DB*} < q_2^{DB*}$ (The gray area in Figure 5). But, in Figure 3, when $0 < \Delta c < \Delta c_1$, there is $p_1^{DB*} > p_2^{DB*}$ (the green area in Figure 3). And, as shown in Figure 6, when $0 < \Delta c < \Delta c_4$, there is $q_1^{RB*} < q_2^{RB*}$ (the gray area in Figure 6). But, in Figure 4, when $0 < \Delta c < \Delta c_2$, there is $p_1^{RB*} > p_2^{RB*}$ (the green area in Figure 4). Comparing the graphs (comparing Figure 3 with Figure 5, comparing Figure 4 with Figure 6), it can be found that the change trend of the threshold value is the same, but the threshold value is different.

When product prices increase, the cost for consumers rises, leading to a decrease in the quantity of the product that consumers are willing to buy at those higher prices. This relationship is known as the law of demand. Conversely, if the price decreases, the product becomes more affordable, and sales are likely to increase as more consumers are willing to purchase the product at the lower price.

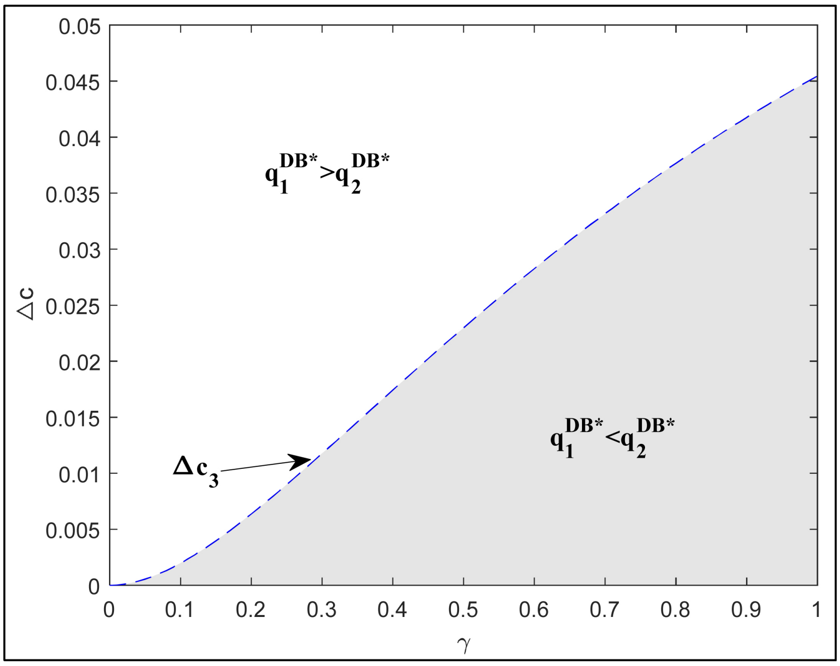


Figure 5. q_1^{DB*} vs. q_2^{DB*}.

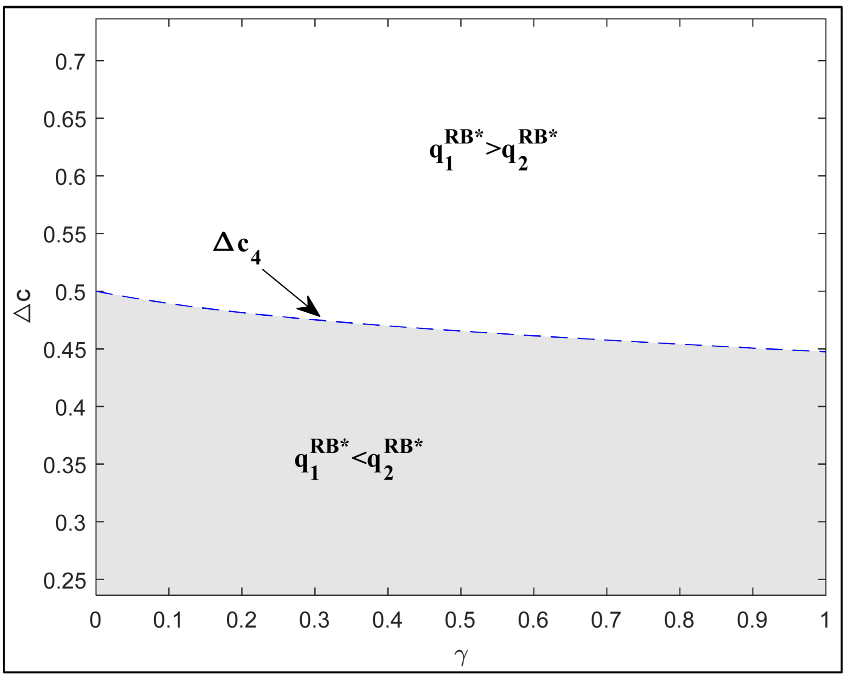


Figure 6. q_1^{RB*} vs. q_2^{RB*}.

Proposition 9. For incumbent manufacturers, the sales volume through direct sales channels surpasses that of distribution channels. However, when the incumbent manufacturer opts for distribution channels, a window of opportunity arises for alternative manufacturers to enter the market and increase their sales volume as well.

Proof. The specific details are shown in **Appendix**.

The reason behind this phenomenon lies in the different dynamics of direct sales channels and distribution channels. Direct sales channels often allow manufacturers to have more control over the sales process and better access to end consumers, leading to higher sales volumes. However, when incumbent manufacturers shift to distribution channels, it may leave gaps in the market that alternative manufacturers can exploit. By seizing this opportunity, alternative manufacturers can increase their market share and sales volume, impacting the performance of the existing manufacturers.

4.4. Profit Comparison between Deploying Blockchain and Not Deploying Blockchain

Is deploying blockchain the best option for supply chains? With this question in mind, in this section, we compare the profits of enterprises in direct sales channels and distribution channels with and without blockchain deployment, respectively. Get the following proposition.

Proposition 10. When $0<\Delta c<\Delta c_5$, there are $\pi_{M_1}^{DB*}>\pi_{M_1}^{DN*}$. When $\Delta c>\Delta c_5$, there is $\pi_{M_1}^{DB*}<\pi_{M_1}^{DN*}$. when $0<\Delta c<\Delta c_6$, there is $\pi_{M_2}^{DB*}<\pi_{M_2}^{DN*}$; when $\Delta c>\Delta c_6$, there is $\pi_{M_2}^{DB*}>\pi_{M_2}^{DN*}$. When $\Delta c_6<\Delta c<\Delta c_5$, The DB model is a win-win choice for both incumbent and alternative manufacturers.

Proof: The specific details are shown in **Appendix**.

Proposition 11. In the distribution channel, when the cost reduction threshold of deploying blockchain is greater than 0 and less than 1 ($0<\Delta c<1$), $\pi_{R/M_1}^{RB*}>\pi_{R/M_1}^{RN*}$, the deployment model is better than the non-deployment model for incumbent manufacturers and distributors. However, when $\Delta c>1$, there is $\pi_{M_2}^{RB*}>\pi_{M_2}^{RN*}$, when the alternative manufacturer enters the market to compete with the incumbent manufacturer, the alternative manufacturer can obtain higher profits.

Proof: The specific details are shown in **Appendix**.

Propositions 10 and 11 show that, under the premise of maximizing profits, deploying blockchain is not necessarily the optimal choice for the supply chain, and there are thresholds that make the profits of manufacturers deploying blockchain higher than those that do not. In the direct sales channel, the deployment of a blockchain model enables incumbent manufacturers and alternative manufacturers to achieve a win-win blockchain cost reduction threshold related to the intensity of product competition (Figure 7), while in the distribution channel, the blockchain cost reduction threshold is a fixed value. In the distribution channel, manufacturers sell products through distributors, which weakens the influence of product competition intensity on the profit decision of the two manufacturers.

In the context of the direct sales channel, the ability of the incumbent manufacturer and the alternative manufacturer to reach a mutually beneficial outcome through blockchain cost reduction is intricately linked to the level of product competition they face. This dynamic nature of the cost reduction threshold in the direct sales channel underscores the importance of strategic decision-making and adaptability in response to competitive pressures. While blockchain offers benefits such as enhanced transparency, security, and efficiency, the decision to deploy it must be carefully evaluated to ensure that the associated costs do not outweigh the potential gains. The concept of a threshold delineates the point at which the financial advantages of blockchain implementation become superior to traditional supply chain practices. Manufacturers must assess this threshold to determine the optimal strategy for their operations, considering factors such as cost savings, market competition, and technological readiness.

In the direct sales channel, where manufacturers interact directly with consumers, the blockchain cost reduction threshold becomes contingent upon the intensity of competition. This relationship underscores the importance of market dynamics in shaping the feasibility and profitability of blockchain adoption for both established and alternative manufacturers. Conversely, within the distribution channel, the cost reduction threshold for deploying blockchain remains constant. This static threshold implies that the benefits derived from implementing blockchain technology in the distribution channel are more consistent and predictable, regardless of the competitive landscape. The fixed nature of this threshold simplifies decision-making processes for manufacturers operating in the distribution channel, providing a more stable framework for assessing the feasibility and impact of blockchain adoption on their operations.

The reason behind this phenomenon can be attributed to the inherent characteristics of direct sales and distribution channels. Direct sales channels typically involve more direct competition between manufacturers, leading to greater variability in the potential benefits of blockchain deployment based on the intensity of competition. On the other hand, distribution channels often entail more standardized and structured relationships between manufacturers and intermediaries, resulting in a more uniform impact of blockchain technology adoption across different competitive scenarios. In general, the diverse cost reduction threshold dynamics observed in direct sales and distribution channels emphasize the significance of taking into account the competitive landscape and channel-specific variables when assessing the feasibility and implications of implementing blockchain technology. By grasping these intricacies and adjusting strategies accordingly, manufacturers can proficiently leverage the capabilities of blockchain to optimize operational efficiency, foster collaboration, and attain sustainable expansion across both direct sales and distribution channels.

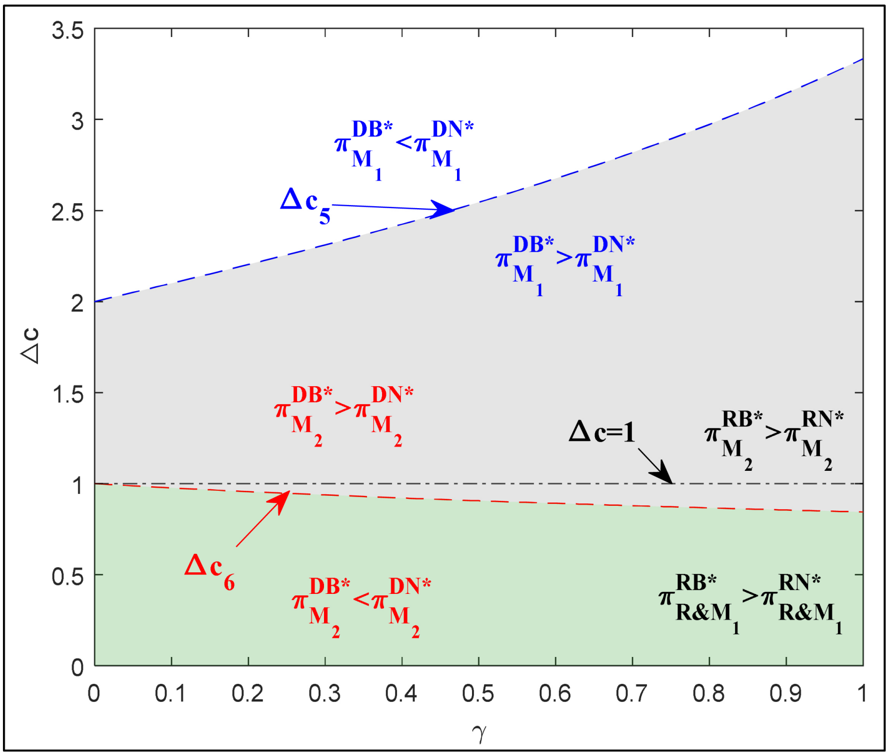


Figure 7. Profits comparison.

5. M_2 Is Allied with M_1 or R

In this section, the static game model is extended from the perspective of supply chain alliance. In addition, as described in the model description section in Section 2, in the extension of this section, F is also considered as the fixed cost of deploying blockchain technology, and T is the privacy concern parameter of consumers, and the model is calculated and analyzed to verify the robustness of the model.

In the context of blockchain deployment, manufacturers of direct sales channels choose to work with the alliance of alternative manufacturers to achieve centralized decision-making in the supply chain, and similarly, distributors and alternative manufacturers of distribution channels work together to achieve centralized decision-making in the supply chain. Note: Use (DB+) to represent the supply chain alliance of the direct sales channel, and (RB+) to represent the supply chain alliance of the distribution channel.

5.1. Deploying Blockchain M_2 and M_1 Alliance (DB+)

In the DB+ model, the alternative manufacturer M_2 and the incumbent manufacturer M_1 alliance jointly decide the product sales price. At this time, the profit function of the supply chain is:

$$Max_{(p_1,p_2)}\pi_{SC}^{DB+} = p_1q_1 + \left(p_2 - \Delta c\right)q_2 - T - F \tag{11}$$

Solve Equation (11) and obtain the optimal equilibrium solution as follows:

$$p_1^{DB+*} = \frac{1}{2},\quad p_2^{DB+*} = \frac{1+\Delta c}{2},\quad \pi_{SC}^{DB+*} = \frac{(\gamma+1)\Delta c^2 - 2\Delta c - 4(T+F) + 2}{4}.$$

5.2. Deploying Blockchain M_2 and R Alliance (RB+)

In the RB+ model, the alternative manufacturer M_2 and the distributor R alliance to jointly decide the product sales price p_1, p_2. At this time, the incumbent manufacturer as the leader decides the wholesale price w of the product, and secondly, the alternative manufacturer M_2 and distributor R as the follower, the alliance decides the distribution price p_1, p_2 of the product. In the RB model, incumbent manufacturers deploy blockchain, and distributors do not bear the corresponding costs, but get the spillover effect of reduced blockchain costs. In the RB+ model in this section, considering that the incumbent manufacturer is responsible for the proportion λ of the total blockchain cost, the distributor bears the remaining proportion $1-\lambda$ of the total cost of the incumbent manufacturer's use of blockchain technology. The profit function of supply chain is:

$$\pi_{M_1}^{RB}(w) = wq_1 - \lambda(T+F) \tag{12}$$

$$Max_{(p_1,p_2)} \pi_{R+M_2}^{RB+} = (p_1 - w)q_1 - (1-\lambda)(T+F) + (p_2 - \Delta c)q_2 \tag{13}$$

Using backward induction to solve, the optimal equilibrium solution is obtained as:

$$w^{RB+*} = \frac{\Delta c\gamma + 1}{2(1+\gamma)},\quad p_1^{RB+*} = \frac{(\Delta c + 2)\gamma + 3}{4+4\gamma},\quad p_2^{RB+*} = \frac{1+\Delta c}{2}$$

$$\pi_{M_1}^{RB+*} = \frac{\Delta c^2\gamma^2 + ((-8F-8t)\lambda + 2\Delta c)\gamma + 1 + (-8F-8t)\lambda}{8+8\gamma}$$

$$\pi_{R+M_2}^{RB+*} = \frac{\Delta c^2\gamma^2 + \left(8\Delta c^2 - 14\Delta c + (16F+16t)\lambda - 16F - 16T + 8\right)\gamma + 4\Delta c^2 - 8\Delta c + (16F+16T)\lambda - 16F - 16T + 5}{16+16\lambda}$$

$$\pi_{SC}^{RB+*} = \frac{3\Delta c^2\gamma^2 + \left(8\Delta c^2 - 16F - 10\Delta c - 16T + 8\right)\gamma + 4\Delta c^2 - 16F - 8\Delta c - 16T + 7}{16+16\lambda}$$

5.3. Comparative Analysis of Channel Alliance Strategies

The purpose of this section is to explore which channel alliance strategy is best for supply chain or alternative manufacturers. When is an alliance the optimal choice for a supply chain?

Proposition 12. For the overall profit of the supply chain, the direct selling channel alliance is more effective than the distribution channel alliance. For alternative manufacturers, there are threshold conditions (δ) that make direct marketing channel alliance or distribution channel alliance optimal: when $0 < \Delta c < \Delta c_{B+}$, distribution channel alliance is the dominant strategy for alternative manufacturers; When $\Delta c > \Delta c_{B+}$, the direct marketing channel alliance is the dominant strategy for alternative manufacturers.

Proof: $\pi_{SC}^{RB+*} - \pi_{SC}^{DB+*} = -\frac{(1+\Delta c\gamma)^2}{16+16\gamma} < 0$, The specific details $\pi_{M_2}^{RB+*} - \pi_{M_2}^{DB+*}$ are shown in **Appendix**.

Proposition 12 can be concluded: For the whole product supply chain, the alternative manufacturer should be the best alliance when the incumbent manufacturer chooses direct sales channel. For alternative manufacturers, there is a threshold condition between which channel to choose and the incumbent enterprise alliance, which is related to the intensity of price competition and the degree of consumer privacy concern. Moreover, for example, in Figure 8, it can be seen that when the consumer privacy concern parameter is $T = 0.2$, the green area separated by the blue dashed line in Figure 8 is the area where the alternative manufacturer chooses the distribution channel alliance. Once the consumer's privacy concerns become large ($T = 0.5$ in Figure 8), the green area separated by the red dashed line in Figure 8 is the area where the alternative manufacturer chooses the distribution channel alliance. We can see that the red dotted line separate green area is greater than the blue dotted line separation of green area, can be intuitive to see the conclusion, as shown in Figure 8, the greater the consumer privacy concerns, the greater the region for alternative manufacturers to choose distribution channel alliance, and the more likely they are to choose distribution channel alliance.

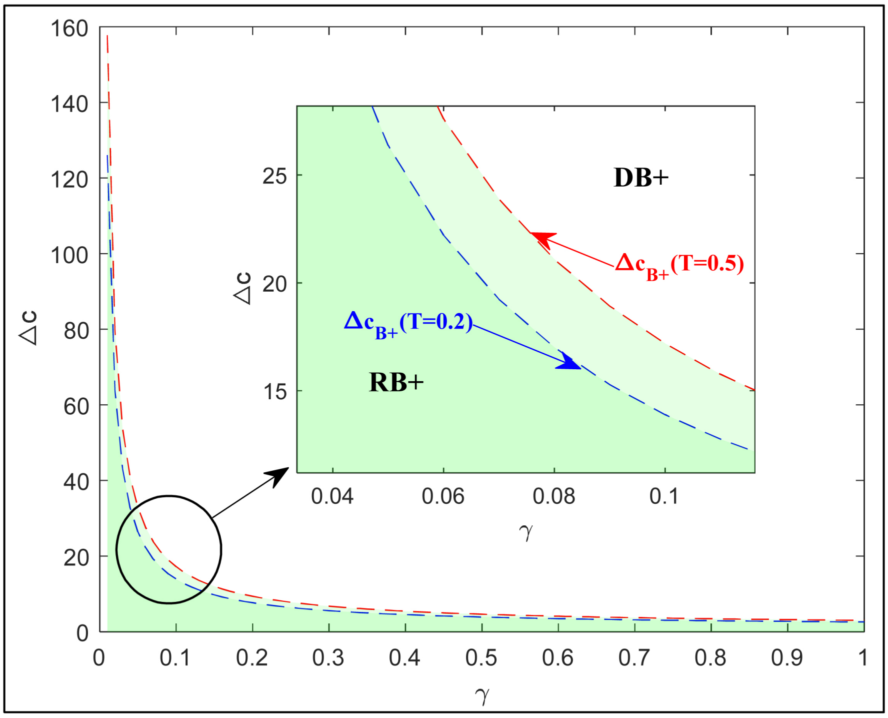


Figure 8. M_2: The threshold region for profit dominance in RB+ or DB+ mode.

Proposition 13. There are certain threshold conditions for the cost reduction of blockchain deployment ($\Delta c > \Delta c_7$), which makes the direct sales channel alliance strategy better than the non-alliance strategy ($\pi_{SC}^{DB+*} > \pi_{SC}^{DB*}$).

Proof: The specific details are shown in **Appendix**.

Proposition 14. There are certain threshold conditions for the cost reduction of deploying blockchain ($\Delta c > \Delta c_8$) that make the distribution channel alliance strategy superior to the non-alliance strategy. The distribution channel alliance strategy is a combination of the falling cost of deploying blockchain, the intensity of product competition, and consumer privacy concerns.

Proof: The specific details are shown in **Appendix**.

Propositions 13 and 14 show that the preconditions for alliance strategies of direct sales channels and distribution channels to be superior to non-alliance strategies are closely related to the reduction in the cost of deploying blockchain and the intensity of product price competition. Under the condition that the cost reduction threshold of blockchain deployment is certain, the greater the competition intensity, the better the alliance selection effect of supply chain node enterprises. But as consumer privacy concerns have grown, so have the advantages of alliances. **Figures 9-12** (where F = 0.5 is set) clearly show the threshold area for selecting alliances under the deployment blockchain decision. **Figure 9** and **Figure 10** show the comparison between non-alliance strategies and alliance strategies of direct marketing channels, and **Figure 11** and **Figure 12** show the comparison between non-alliance strategies and alliance strategies of distribution channels. **Figures 9-11** are (on the premise of changes in the intensity of price competition) the impact of two parameters, consumer privacy concerns and blockchain reduction of unit costs, on whether the two channels are allied in the decision area. It can be seen that the greater the intensity of price competition, the larger the decision-making region of the alliance for the two channels (for example, the red dotted line $\gamma = 0.8$ in **Figure 9**, above which is the decision-making area DB+ of the direct marketing channel alliance). In **Figure 9**, the blue solid line $\gamma = 0.5$, above which is DB+, the decision-making area of the direct marketing channel alliance. Comparing the two lines, it can be found that the red dotted line is lower than the blue solid line on the whole, that is, the greater the intensity of price competition, the larger the alliance's decision-making area DB+) (**Figure 11** is the same). **Figure 10** and **Figure 11** are (on the premise of changes in consumer privacy concerns parameters) the impact of price competition intensity and blockchain reduction of unit cost on the decision area of whether the two channels are allied. It can be seen that when the consumer privacy concern parameter is larger, the decision-making area of the alliance becomes smaller for the two channels (for example, the red dotted line $T = 0.8$ in **Figure 10**, above which is the decision-making area DB+ of the direct marketing channel alliance). In **Figure 10**, the blue solid line $T = 0.5$, above which is DB+, the decision-making area of the direct marketing channel alliance. Comparing the two lines, it can be found that the red dotted line is higher than the blue solid line on the whole, that is, the larger the consumer privacy concern parameter, the smaller the alliance's decision area DB+) (**Figure 12** is the same). Interestingly, under the two channels, when the intensity of product price competition changes in the interval (0, 1), the threshold curve of whether to choose alliance strategy shows an "L"-shaped trend.

Intuitively, comparing Figure 9 with Figure 11, and comparing Figure 10 with Figure 12, it can be seen that the change trend of alliance threshold under the two sales models is the same, but the threshold value has changed. In addition, by comparing Figures 9-12, we can find that by observing its ordinate, the supply chain alliance threshold of direct selling channel is higher than that of distribution channel.

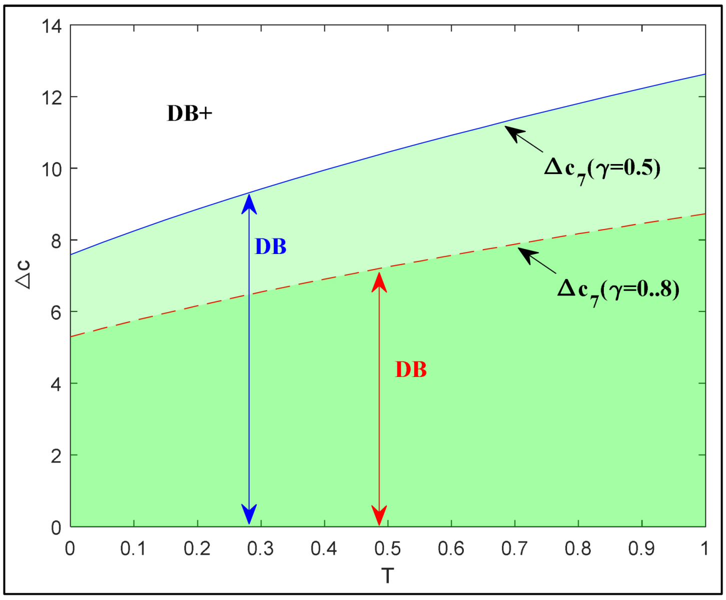


Figure 9. Profits: DB+ vs. DB.

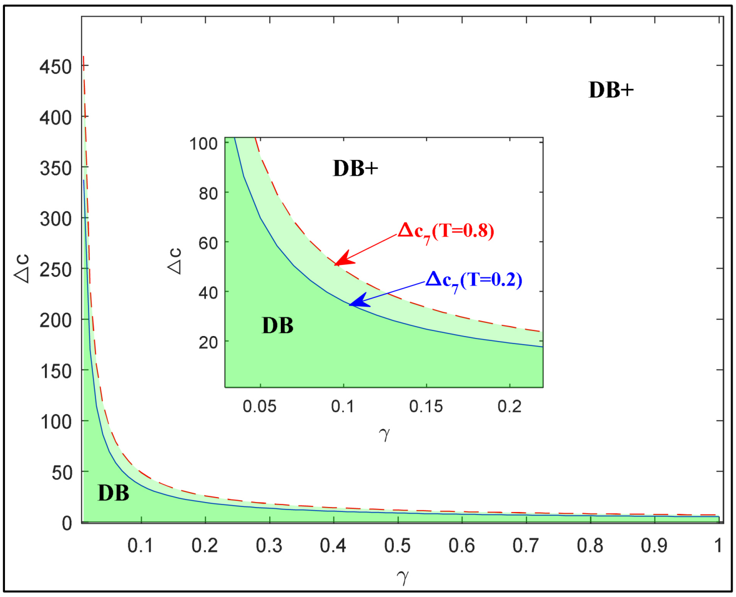


Figure 10. Profits: DB+ vs. DB $\gamma \in (0,1)$.

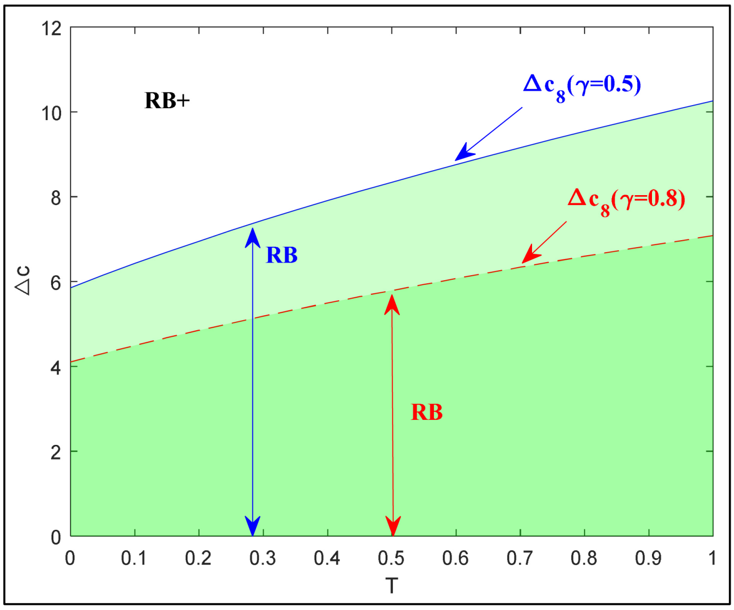


Figure 11. Profits: RB+ vs. RB.

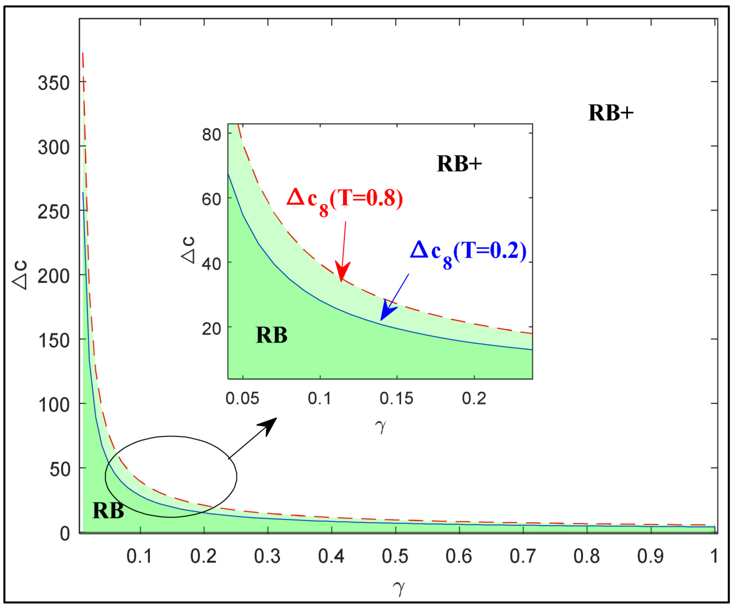


Figure 12. Profits: RB+ vs. RB $\gamma \in (0,1)$.

6. Model Extension—Dynamic Game Analysis of Alliance

The static game model is used to analyze whether the alternative manufacturer chooses alliance strategy and which channel alliance strategy is optimal. Standing on the premise of the optimal profit of the whole supply chain, this paper gets the conclusion that the direct selling channel alliance is better than the distribution channel alliance. Standing on the premise of the optimal profit of the alternative manufacturer, this paper obtains that there are threshold conditions Δc_{B+} for the dominance of the direct selling channel alliance or the distribution channel alliance. This section intends to use the dynamic game to analyze the dynamic evolutionary game between the incumbent manufacturer and the incumbent manufacturer by using the optimal profit equilibrium solution of the incumbent manufacturer. It is proposed that in the long-term dynamic evolutionary game, under what circumstances is the direct selling (distribution) channel alliance optimal for alternative manufacturers? And, dynamic decisions about whether or not existing manufacturers deploy blockchain? Finally, the evolutionary game stability strategy of incumbent manufacturers and alternative manufacturers is obtained, which provides decision-making suggestions for enterprises to make long-term decisions.

6.1. Construction of Dynamic Game—Evolutionary Game Model

The incumbent manufacturer's action strategy is (deploy blockchain, do not deploy blockchain). The action strategy of alternative manufacturers is (direct sales channel alliance, distribution channel alliance). The two-dimensional matrix strategies of evolutionary game participants are shown in Table 3. The expression of the evolutionary game model as follow, see Table 4 (Note, the profit expression of the DN+ and RN+ models is shown in **Appendix**).

Table 3. Evolutionary game matrix strategy.

Matrix strategy		M_2 channel alliance	
		Direct selling channel alliances (y)	Distribution channel alliance (1 − y)
Whether M_1 deploys blockchain	Deploy the blockchain (x)	DB+	RB+
	Blockchains are not deployed (1 − x)	DN+	RN+

Table 4. Expression of evolutionary game matrix strategy.

Model and manufacturer	M_1	M_2
DB+	$\pi_{M_1}^{DB+*}=\dfrac{\Delta c\gamma-2(T+F)+1}{4}$	$\pi_{M_2}^{DB+*}=\dfrac{\Delta c^2(1+\gamma)-(2+\gamma)\Delta c-2(T+F)+1}{4}$
RB+	$\pi_{M_1}^{RB+*}=\dfrac{\Delta c^2\gamma^2+((-8F-8T)\lambda+2\Delta c)\gamma+1+(-8F-8T)\lambda}{8+8\gamma}$	$\pi_{M_2}^{RB+*}=\dfrac{(\Delta c-1)(\Delta c\gamma^2+(4\Delta c-3)\gamma+2\Delta c-2)}{8+8\gamma}$
DN+	$\pi_{M_1}^{DN+*}=\dfrac{(\Delta c-1)^2}{4}$	$\pi_{M_2}^{DN+*}=\dfrac{(\Delta c-1)^2}{4}$
RN+	$\pi_{M_1}^{RN+*}=\dfrac{(-1+(\gamma+2)\Delta c)^2}{8+8\gamma}$	$\pi_{M_2}^{RN+*}=\dfrac{(\Delta c-1)(-\Delta c\gamma^2+(2\Delta c-3)\gamma+2\Delta c-2)}{8+8\gamma}$

According to the previous description and evolutionary game theory:

1) The expected benefits of incumbent manufacturers deploying blockchain: $W_1=y\pi_{M_1}^{DB+*}+(1-y)\pi_{M_1}^{RB+*}$, Expected benefits of incumbent manufacturers not

deploying blockchains: $W_2 = y\pi_{M_1}^{DN+*} + (1-y)\pi_{M_1}^{RN+*}$. The incumbent manufacturer expects to receive the following benefits: $\overline{W} = xW_1 + (1-x)W_2$, i.e.

$$\frac{dx}{dt} = x\left(W_1 - \overline{W}\right) = x(1-x)\left[\left(\pi_{M_1}^{DB+*} - \pi_{M_1}^{DN+*} - \pi_{M_1}^{RB+*} + \pi_{M_1}^{RN+*}\right)y + \pi_{M_1}^{RB+*} - \pi_{M_1}^{RN+*}\right]$$

2) In the same way, the profit of the alternative manufacturer is:

$$\frac{dy}{dt} = x\left(W_1' - \overline{W}'\right) = y(1-y)\left[\left(\pi_{M_2}^{DB+*} - \pi_{M_2}^{DN+*} - \pi_{M_2}^{RB+*} + \pi_{M_2}^{RN+*}\right)x + \pi_{M_2}^{DN+*} - \pi_{M_2}^{RN+*}\right]$$

Simultaneous $\frac{dx}{dt}, \frac{dy}{dt}$ constitutes a two-dimensional dynamical system, so that $\frac{dx}{dt} = 0, \frac{dy}{dt} = 0$, solving (0, 0), (0, 1), (1, 0), and (1, 1) are the four pure strategic equilibrium points of the system. (This section mainly substitutes the dynamic conditions for which alliance strategy is optimal for the manufacturer to choose under what circumstances, so this section only analyzes the pure strategy equilibrium point, not the mixed equilibrium point.)

According to the system theory of differential equations proposed by Friedman, the stability of the equilibrium point is judged by analyzing the determinants ($Det(J)$) and traces ($Tr(J)$) of the Jacobian matrix of the system. When the equilibrium point is satisfied $Det(J) > 0$, $Tr(J) < 0$, it is an Evolutionarily Stable Strategy (ESS), that is, the point is in the state of Evolutionarily Stable Strategy. Jacobian matrix as follows:

$$J = \begin{bmatrix} \frac{\partial^2 x}{\partial t \partial x} & \frac{\partial^2 x}{\partial t \partial y} \\ \frac{\partial^2 y}{\partial t \partial x} & \frac{\partial^2 y}{\partial t \partial y} \end{bmatrix}$$

$$\frac{\partial^2 x}{\partial t \partial x} = (1-2x)\left[\left(\pi_{M_1}^{DB+*} - \pi_{M_1}^{DN+*} - \pi_{M_1}^{RB+*} + \pi_{M_1}^{RN+*}\right)y + \pi_{M_1}^{RB+*} - \pi_{M_1}^{RN+*}\right]$$

$$\frac{\partial^2 x}{\partial t \partial y} = x(1-x)\left(\pi_{M_1}^{DB+*} - \pi_{M_1}^{DN+*} - \pi_{M_1}^{RB+*} + \pi_{M_1}^{RN+*}\right)$$

$$\frac{\partial^2 y}{\partial t \partial x} = y(1-y)\left(\pi_{M_2}^{DB+*} - \pi_{M_2}^{DN+*} - \pi_{M_2}^{RB+*} + \pi_{M_2}^{RN+*}\right)$$

$$\frac{\partial^2 y}{\partial t \partial y} = (1-2y)\left[\left(\pi_{M_2}^{DB+*} - \pi_{M_2}^{DN+*} - \pi_{M_2}^{RB+*} + \pi_{M_2}^{RN+*}\right)x + \pi_{M_2}^{DN+*} - \pi_{M_2}^{RN+*}\right]$$

Bringing four pure strategy equilibrium points into the Jacobian matrix yields $Det(J)$ and $Tr(J)$ for each equilibrium point, as shown in Table 5.

6.2. Threshold Analysis—Stable Point Judgment of Evolutionary Game

In this section, the stability point of evolutionary game model is determined. If the equilibrium point is a stable point, the threshold condition of the equilibrium point is analyzed by using the inverse derivation method. It is worth noting that the formula of the model is complex, and numerical assignment is used to show

Table 5. $Det(J)$ and $Tr(J)$ for each equilibrium point.

Equilibrium point	$Det(J)$	$Tr(J)$
(0, 0)	$\left(\pi_{M_1}^{RB+*}-\pi_{M_1}^{RN+*}\right)\left(\pi_{M_2}^{DN+*}-\pi_{M_2}^{RN+*}\right)$	$\left(\pi_{M_1}^{RB+*}-\pi_{M_1}^{RN+*}\right)+\left(\pi_{M_2}^{DN+*}-\pi_{M_2}^{RN+*}\right)$
(0, 1)	$\left(\pi_{M_1}^{DB+*}-\pi_{M_1}^{DN+*}\right)\left[-\left(\pi_{M_2}^{DN+*}-\pi_{M_2}^{RN+*}\right)\right]$	$\left(\pi_{M_1}^{DB+*}-\pi_{M_1}^{DN+*}\right)+\left[-\left(\pi_{M_2}^{DN+*}-\pi_{M_2}^{RN+*}\right)\right]$
(1, 0)	$-\left[\pi_{M_1}^{RB+*}-\pi_{M_1}^{RN+*}\right]\left(\pi_{M_2}^{DB+*}-\pi_{M_2}^{RB+*}\right)$	$-\left[\pi_{M_1}^{RB+*}-\pi_{M_1}^{RN+*}\right]+\left(\pi_{M_2}^{DB+*}-\pi_{M_2}^{RB+*}\right)$
(1, 1)	$\left[-\left(\pi_{M_1}^{DB+*}-\pi_{M_1}^{DN+*}\right)\right]\left[-\left(\pi_{M_2}^{DB+*}-\pi_{M_2}^{RB+*}\right)\right]$	$\left[-\left(\pi_{M_1}^{DB+*}-\pi_{M_1}^{DN+*}\right)\right]+\left[-\left(\pi_{M_2}^{DB+*}-\pi_{M_2}^{RB+*}\right)\right]$

the threshold region when analyzing the conditional threshold of the stable point. Among them, (0, 0) and (1, 1) are not stable points, and detailed proof of threshold analysis for the judgment of stable points in evolutionary games will be given in detail in **Appendix**.

(0, 1) is the threshold condition for the stable point. In the case of $\Delta c>1$, $1<\Delta c<y_1 \cup \Delta c>y_2$, $Det>0$ & $Tr<0$, (0, 1) is the stable point. After analysis, as shown in Figure 13 and Figure 14, within the range $\Delta c>1$, except the areas one and two besieged by the gray area (parameter assignment of the threshold range $\lambda=0.8$, $F=0.5$, $\gamma=0.5$ & 0.8). It can be seen that the size of the stable region (0, 1) is related to the intensity of price competition γ, and as γ changes, the threshold of its independent variable (the degree of consumer privacy concern) also changes.

(1, 0) is the threshold condition of the stable point. Under condition $0<\lambda<\frac{1}{2}$, when $y_1'<\Delta c<y_2'$, $det>0$, $tr<0$, (1, 0) is the stable point (region one in Figure 15). (Parameter assignment for threshold range $\gamma=0.8$, $F=0.5$, $\lambda=0.2$).

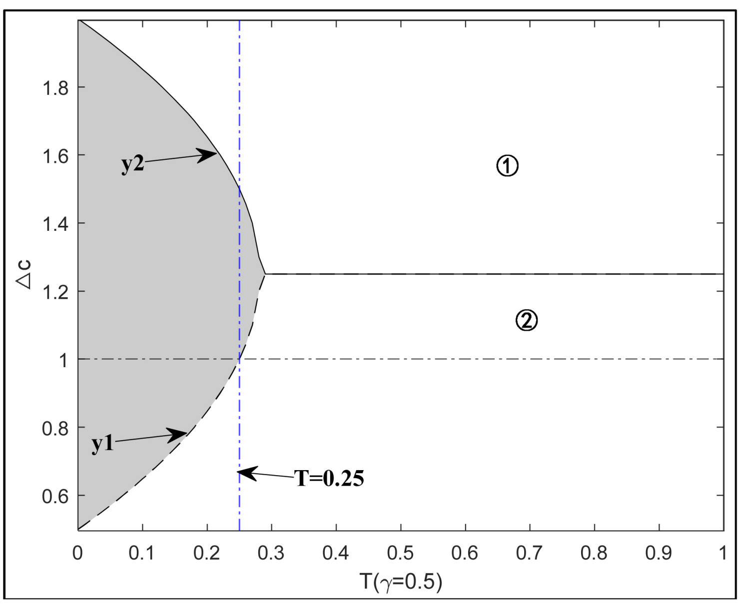


Figure 13. Threshold region of (0, 1), $\gamma=0.5$.

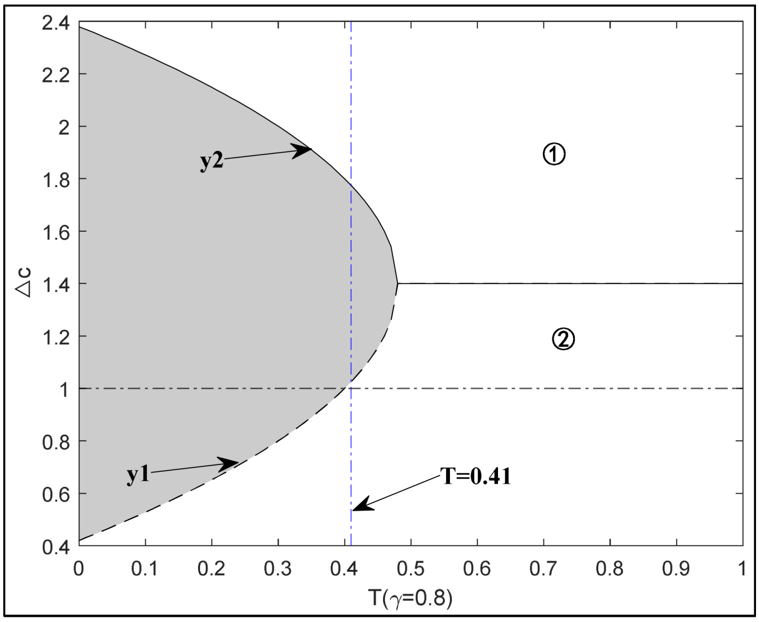


Figure 14. Threshold region of (0, 1), $\gamma = 0.8$.

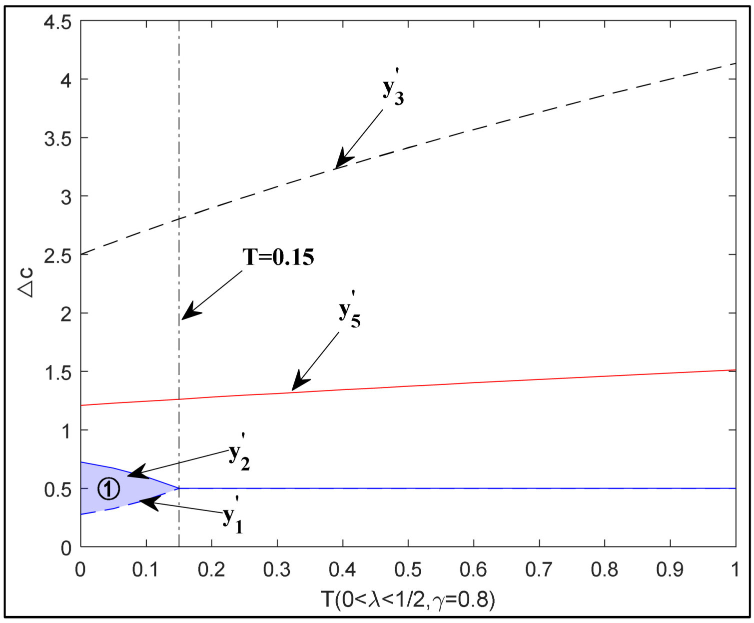


Figure 15. The threshold region of the stable point (1, 0), $\lambda = 0.2$.

(1, 0) is the stable point, that is, the incumbent manufacturer chooses to deploy the blockchain strategy, and the alternative manufacturer chooses the distribution channel alliance strategy. It is found that only when the incumbent manufacturer's own complex blockchain total cost ratio is between $0 < \lambda < \frac{1}{2}$, the conclusion that (1, 0) is a stable point is reached. That is, this paper concludes that incumbent manufacturers will benefit most if they are responsible for less than 1/2 of the total cost of blockchain.

6.3. Dynamic Game—Evolutionary Game Numerical Simulation

1) (0, 1) Numerical simulation of stable points. Under the premise of $\Delta c > 1$, $1 < \Delta c < y_1 \cup \Delta c > y_2$, $Det > 0$ & $Tr < 0$. Therefore, the numerical simulation is assigned: $\gamma = 0.8$, $F = 0.5$, $\lambda = 0.8$, $T = 0.5$. The evolutionary stability trend diagram of different Δc was analyzed, as shown in Figure 16.

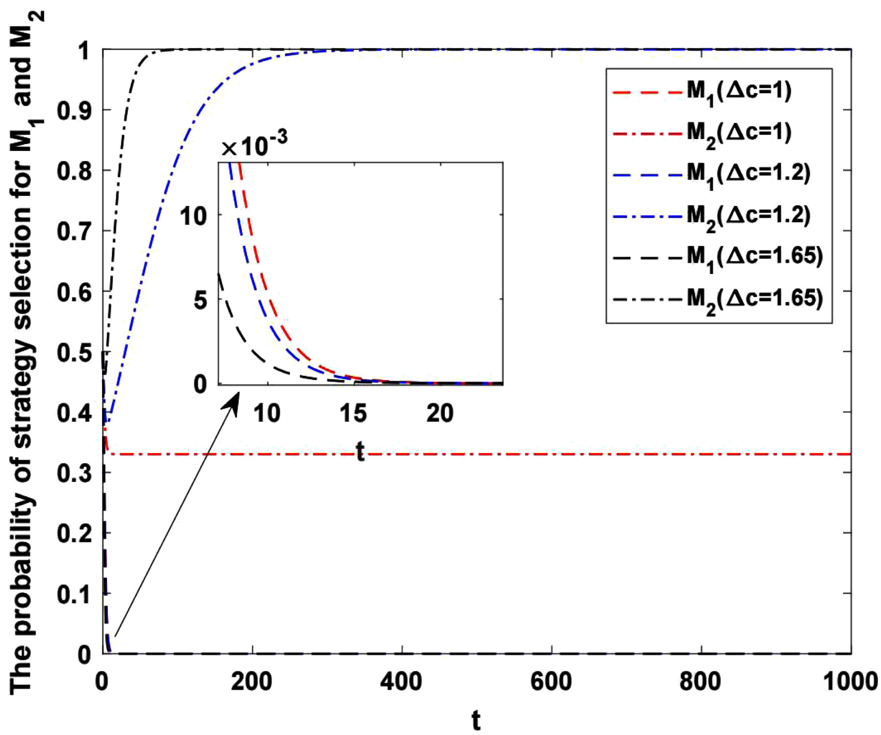


Figure 16. Evolution trend diagram of stable point (0, 1).

It can be seen that, $\Delta c = 1$, the threshold condition of stable point (0, 1) is not satisfied, which is reduced to an unstable state in Figure 16. When the premise $\Delta c > 1$ is satisfied, $1 < \Delta c < y_1 \cup \Delta c > y_2$, that is, $\Delta c = 1.2$ and $\Delta c = 1.65$ in Figure 16, the stable state of the evolutionary game is (0, 1). The larger Δc is, the faster the incumbent manufacturer and the alternative manufacturer converge to the evolutionarily stable state (0, 1).

2) (1, 0) Numerical simulation of stable points. Under conditions $0 < \lambda < \frac{1}{2}$, $y_1' < \Delta c < y_2'$. $det > 0$, $tr < 0$. Therefore, the numerical simulation is assigned: $\gamma = 0.8$, $F = 0.5$, $\lambda = 0.2$, $T = 0.1$, $\Delta c = 0.5$. Figure 17 shows the evolution trend of (1, 0). As can be seen from Figure 17 (The red line in Figure 17 has an initial probability of 0.7, and the black line in Figure 17 has an initial probability of 0.5.), the initial probabilities are different, and the stable state of the evolutionary game is (1, 0), that is, the incumbent manufacturer chooses to deploy the blockchain strategy, and the alternative manufacturer chooses the distribution channel alliance strategy. As can be seen in Figure 18, once $\lambda \geq \frac{1}{2}$ (The red line

in **Figure 18**), the stable state of the evolutionary game changes from (1, 0) to (0, 0), that is, from the strategic combination (the incumbent manufacturer deployes blockchain and replaces the manufacturer's distribution channel alliance) to the strategic combination (the incumbent manufacturer does not deploy blockchain and replaces the manufacturer's distribution channel alliance).

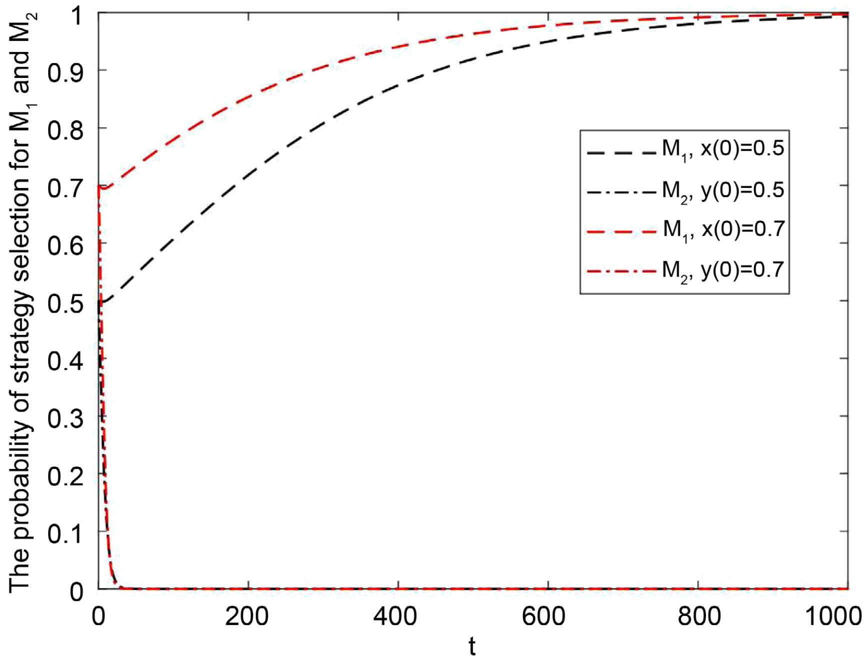


Figure 17. Evolution trend of stable point (1, 0).

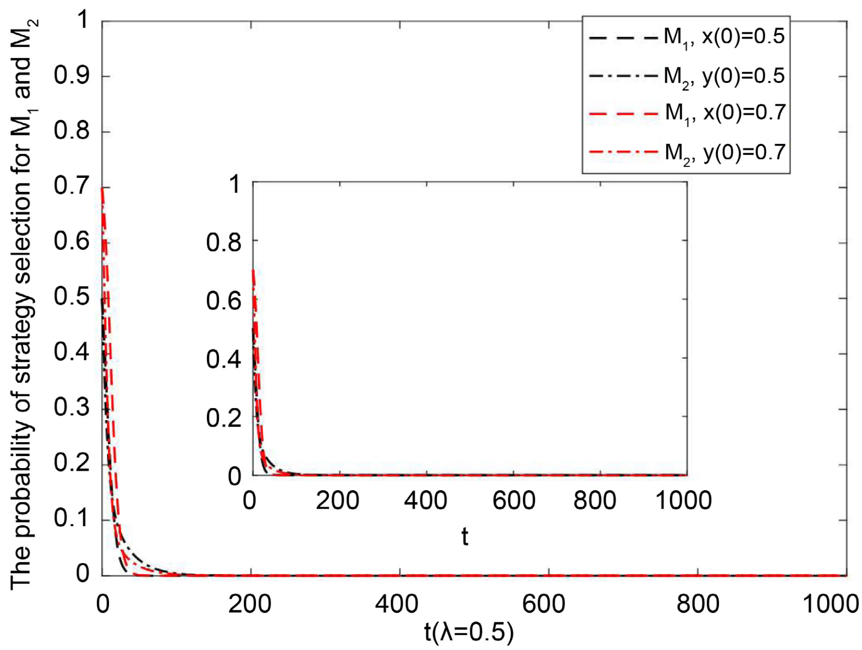


Figure 18. Evolution trend when $\lambda \geq \frac{1}{2}$.

The static game shows that there are certain threshold conditions Δc_{B+} for alternative manufacturers to choose direct marketing channel alliance or distribution channel alliance. The dynamic game concludes that in the long run, when deploying blockchain, it is always optimal for alternative manufacturers to choose distribution channel alliances, and distribution channel alliances are win-win for game participants (incumbent manufacturers and alternative manufacturers). In the long run, when existing manufacturers choose distribution channels for product sales, manufacturers deploy blockchain, and at this time, alternative manufacturers choose to jointly decide the product sales price with the distributor alliance, which is the most sensible choice.

7. Conclusion and Future Research

7.1. Conclusion

In this paper, static game and dynamic game are used to study the competition and cooperation between two manufacturers. In it, the incumbent manufacturer sells products through two channels: direct sales and distribution, and the incumbent manufacturer decides whether to deploy blockchain. Under these two channels, the alternative manufacturer competes with the incumbent manufacturer on product price, and the alternative manufacturer also has a choice to decide whether to make alliance with the incumbent supply chain, that is, the direct sales channel alliance or the distribution channel alliance. There are four static game modes, and the optimal result of price decision and product sales decision of two manufacturers is obtained by comparing and analyzing the equilibrium solution of four static game modes. In addition, on the basis of the basic model, the model is extended from two aspects: the first extension is from the static game point of view, to replace the manufacturer and the incumbent supply chain enterprise alliance to make centralized supply chain decision (replace the manufacturer and the incumbent supply chain enterprise alliance (direct sales channel alliance); alternative manufacturers and distributors alliance (distribution channel alliance). The second extension is from the perspective of dynamic game, the alternative manufacturer and the incumbent manufacturer conduct dynamic evolutionary game from the perspective of maximizing their own profits. The dynamic game strategy of the incumbent manufacturer is (deploying blockchain, not deploying blockchain), and the dynamic game strategy of the alternative manufacturer is (direct marketing channel alliance, and distribution channel alliance). The main conclusions are as follows.

Price competition. 1) In direct sales channels, when blockchain is not deployed, the condition of blockchain cost reduction threshold is fixed, and the cost reduction threshold of blockchain deployment (Δc_1) is related to the intensity of product price competition (the greater the intensity of competition, the greater the blockchain cost reduction threshold). In the distribution channel, when blockchain is not deployed, the selling price of the existing product is always higher than the selling price of the alternative manufacturer; when deploying blockchain, the condition that the selling price of the existing product is higher than the selling price of the competing product is correlated with the cost reduction threshold (Δc_2) (the greater the intensity of price competition, the smaller the blockchain cost reduction threshold). This is contrary to the changing trend of the blockchain cost reduction threshold in the direct sales channel. 2) In both sales channels, products integrated with blockchain technology consistently exhibit lower selling prices compared to products without such integration. 3) For incumbent manufacturers, irrespective of the adoption of blockchain technology, product pricing in distribution channels consistently surpasses that in direct sales channels. Furthermore, in the scenario where the incumbent manufacturer opts for distribution channel sales, it presents an opening for alternative manufacturers to enter the market, leading to an escalation in both the competition and pricing of the alternative manufacturer's offerings.

Channel selection. 1) When not deploying blockchain technology, under the combined influence of high blockchain cost reduction thresholds and intense price competition, incumbent manufacturers should opt for distribution channels for product sales based on maximizing their own profits. 2) On the other hand, when deploying blockchain technology, and aiming to maximize profits, direct sales channels consistently emerge as the optimal choice for incumbent manufacturers. By directly engaging with customers, they can capture the full value generated by blockchain deployment, maintain better control over pricing strategies, and establish closer relationships with end-users to drive brand loyalty and repeat purchases.

Decision to deploy blockchain. In the pursuit of profit maximization, the decision to implement blockchain technology within the supply chain may not always represent the most advantageous choice. There exists a critical threshold where the profitability of manufacturers, when employing blockchain, surpasses that of manufacturers operating without blockchain integration. Within the direct sales channel, the threshold for cost reduction through blockchain adoption, leading to mutual benefits for both incumbent and alternative manufacturers, is intricately linked to the competitive landscape within the product market. Conversely, in the distribution channel, the cost reduction threshold for blockchain implementation remains a constant value, unaffected by competitive dynamics.

Alliance decision. 1) In a static game analysis, the optimal channel alliance and the threshold conditions under which alliance decisions are superior to non-alliance decisions when deploying blockchain technology are explored. From the perspective of centralized supply chain decision-making, for the overall profit of the supply chain, it is more effective for alternative manufacturers to choose a direct sales channel alliance rather than a distribution channel alliance. 2) Additionally, under certain conditions of decreasing blockchain deployment costs, the greater the intensity of competition, the better the alliance effect. However, as consumer privacy concerns increase, the advantages of alliances are weakened. 3)

Interestingly, under the two channels, when the intensity of product price competition changes in the interval (0, 1), the threshold curve of the dominance of the alliance strategy of the overall profit of the supply chain presents an "L"-shaped change trend. From the perspective of alternative manufacturers themselves, there are certain threshold conditions Δc_{B+} for alternative manufacturers to choose direct marketing channel alliance or distribution channel alliance, and the alternative manufacturers to choose direct marketing channel alliance or distribution channel alliance strategy also presents an "L" type change trend. 4) In the dynamic evolutionary game, the dynamic evolutionary game explores which channel alliance is better and whether the incumbent manufacturer deploys blockchain: From the perspective of maximizing the profits of the two manufacturers, the stable strategy of the evolutionary game is the (0, 1) and (1, 0) strategy, that is, when the incumbent manufacturer does not deploy blockchain, the alternative manufacturer direct sales channel alliance is the best strategy; When the incumbent manufacturer deploys blockchain, the alternative manufacturer chooses the distribution channel alliance as the optimal strategy, and the incumbent manufacturer will only get a stable strategy (deploying blockchain, distribution channel alliance) when the proportion of the total cost of blockchain is less than 1/2.

7.2. Management Implications

First, this paper highlights the competitive dynamics and strategic interactions between existing and alternative manufacturers in the context of blockchain deployment, channel selection, and pricing strategies, highlights the impact of blockchain technology on pricing strategy and channel decisions, and emphasizes the importance of strategic positioning and market competitive responses. For incumbent manufacturers, it is crucial to carefully assess the cost-benefit trade-offs associated with blockchain deployment and channel selection. Prioritizing a thorough analysis of market dynamics, cost structures, and competitive landscapes can help them make informed decisions that align with their strategic objectives and financial goals.

Second, for alternative manufacturers, it is essential to carefully consider the dynamics of the market, cost structures, and competitive environment when making decisions regarding channel alliances in the context of blockchain deployment. Here are some recommendations for alternative manufacturers: 1) Evaluate alliance options: conduct a thorough analysis to compare the potential benefits and drawbacks of forming alliances with direct sales channels versus distribution channels. Consider factors such as market reach, cost-effectiveness, and competitive positioning to determine the most suitable alliance strategy. 2) Monitor blockchain deployment costs: keep a close eye on the evolving costs associated with blockchain implementation. Identify the threshold at which the cost reduction becomes significant enough to justify alliance decisions and leverage the benefits of blockchain technology in enhancing supply chain efficiency and transparency. 3) Address consumer privacy concerns: proactively address and mitigate consumer privacy concerns by implementing robust data protection measures and transparent communication strategies within the alliance framework. Building trust with consumers is crucial for sustaining long-term relationships and loyalty. 4) Adapt to competitive intensity: recognize the impact of competitive intensity on alliance effectiveness and adjust strategies accordingly. In highly competitive markets, focus on differentiation, innovation, and customer-centric approaches to maintain a competitive edge within the alliance network. By carefully assessing these factors and aligning alliance decisions with strategic goals, alternative manufacturers can leverage blockchain technology and channel alliances to optimize supply chain performance, enhance profitability, and adapt to evolving market dynamics effectively.

Third, based on the dynamic evolutionary game analysis, here are some tailored recommendations. For incumbent manufacturer, 1) conduct a comprehensive evaluation of the advantages of implementing blockchain technology: analyze the potential benefits associated with integrating blockchain into supply chain operations, focusing on enhancing transparency, efficiency, and cost-effectiveness. Take into account the implications for alliance strategies and competitive positioning while making informed decisions regarding the deployment of blockchain technology. 2) Strategic alliance formation: understand the implications of forming different types of channel alliances based on the deployment of blockchain technology. Collaborate with alternative manufacturers to explore mutually beneficial alliance structures that align with strategic goals and maximize profitability. 3) Cost sharing in blockchain deployment: ensure that the cost-sharing mechanism for blockchain deployment is equitable and aligns with the stability of alliance strategies. Maintain transparency and open communication with alternative manufacturers to foster trust and cooperation in the deployment process. For alternative manufacturer: 1) Adjust alliance strategies: Customize partnership approaches according to the implementation progress of blockchain technology by the existing manufacturer. Maintain adaptability and readiness to transition between direct sales channel partnerships and distribution channel collaborations to maximize profitability and competitive edge. Switching between direct sales channel alliances and distribution channel collaborations allows organizations to adapt to market dynamics, customer preferences, and technological advancements effectively. Direct sales channel alliances may offer greater control over customer relationships and branding, while distribution channel alliances can provide broader market reach and operational efficiencies. By strategically navigating between these alliance models based on the progress of blockchain implementation, organizations can enhance their revenue streams, expand market presence, and strengthen their competitive position in the industry. 2) Collaborate on blockchain implementation: work closely with the incumbent manufacturer to understand the implications of blockchain deployment on alliance dynamics. Collaborate on cost-sharing mechanisms and strategic planning to ensure a smooth transition to the most optimal alliance strategy. 3) Monitor cost-benefit ratio: keep a close watch on the cost-benefit ratio of blockchain deployment in relation to alliance strategies. Ensure that the stability of alliance strategies is maintained within the specified cost-sharing thresholds to maximize mutual benefits and long-term cooperation. By following these recommendations and adapting strategies based on the dynamic evolution of the game, both the incumbent and alternative manufacturers can navigate the complexities of channel alliances and blockchain deployment decisions effectively to achieve mutual profitability and sustainable competitive advantage.

7.3. The Prospect of Future Research

First, because the key purpose of this paper is to explore the combined impact of three parameters (the degree of cost reduction for incumbent manufacturers to deploy blockchain, the intensity of price competition, and the degree of consumer privacy concerns about blockchain) on supply chain channel choice and alliance strategy choice, rather than the impact of different unit costs between incumbent and alternative manufacturers on decision making, in order to simplify the model, in this model, the unit cost of incumbent manufacturers and alternative manufacturers are equal, but there are different costs in real life. However, it overlooks the influence of consumers' strategic behaviors on manufacturers' sales strategies and the effects of blockchain technology deployment on product quality determinations. Future investigations should delve deeper into these dimensions for a more comprehensive understanding.

Moreover, while the current study sheds light on the competitive and collaborative interactions between two manufacturers in the blockchain landscape, it fails to account for the pivotal role of consumers' strategic behaviors in shaping manufacturers' sales strategies. Understanding how consumer preferences, purchasing patterns, and decision-making processes influence manufacturers' alliance choices and market positioning is essential for crafting customer-centric strategies that drive growth and competitiveness.

Furthermore, the impact of deploying blockchain technology on product quality decisions represents a critical yet overlooked aspect in the current study. Assessing how blockchain implementation influences quality control processes, product traceability, and consumer trust can provide valuable insights into enhancing product offerings, ensuring compliance with industry standards, and fostering customer loyalty. Future research endeavors should explore this dimension in greater depth to uncover the full spectrum of implications for manufacturers operating in blockchain-enabled environments.

Data Availability Statement

The data used to support the findings of this study are available from the corresponding author upon request.

Acknowledgements

The authors are grateful to the Editor and reviewers for their very valuable comments and suggestions. The authors are grateful for the partial financial support from Supported by the Major Program of the National Social Science Foundation of China (23&ZD138).

Conflict of Interest Statement

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

Bakshi, N., & Kleindorfer, P. (2009). Co-Opetition and Investment for Supply-Chain Resilience. *Production and Operations Management, 18,* 583-603. https://doi.org/10.1111/j.1937-5956.2009.01031.x

Cui, Y., Hu, M., & Liu, J. (2023). Value and Design of Traceability-Driven Blockchains. *Manufacturing & Service Operations Management, 25,* 1099-1116. https://doi.org/10.1287/msom.2022.1161

De Giovanni, P. (2020). Blockchain and Smart Contracts in Supply Chain Management: A Game Theoretic Model. *International Journal of Production Economics, 228,* Article ID: 107855. https://doi.org/10.1016/j.ijpe.2020.107855

Dong, L., Jiang, P., & Xu, F. (2023). Impact of Traceability Technology Adoption in Food Supply Chain Networks. *Management Science, 69,* 1518-1535. https://doi.org/10.1287/mnsc.2022.4440

Gong, B., Zhang, H., Gao, Y., & Liu, Z. (2023). Blockchain Adoption and Channel Selection Strategies in a Competitive Remanufacturing Supply Chain. *Computers & Industrial Engineering, 175,* Article ID: 108829. https://doi.org/10.1016/j.cie.2022.108829

Li, Z., Xu, X., Bai, Q., Guan, X., & Zeng, K. (2021). The Interplay between Blockchain Adoption and Channel Selection in Combating Counterfeits. *Transportation Research Part E: Logistics and Transportation Review, 155,* Article ID: 102451. https://doi.org/10.1016/j.tre.2021.102451

Luo, Z., Chen, X., & Wang, X. (2016). The Role of Co-Opetition in Low Carbon Manufacturing. *European Journal of Operational Research, 253,* 392-403. https://doi.org/10.1016/j.ejor.2016.02.030

Mantovani, A., & Ruiz-Aliseda, F. (2016). Equilibrium Innovation Ecosystems: The Dark Side of Collaborating with Complementors. *Management Science, 62,* 534-549. https://doi.org/10.1287/mnsc.2014.2140

Niu, B., Dong, J., Dai, Z., & Jin, J. Y. (2022). Market Expansion vs. Intensified Competition: Overseas Supplier's Adoption of Blockchain in a Cross-Border Agricultural Supply Chain. *Electronic Commerce Research and Applications, 51,* Article ID: 101113. https://doi.org/10.1016/j.elerap.2021.101113

Pun, H., Swaminathan, J. M., & Hou, P. (2021). Blockchain Adoption for Combating Deceptive Counterfeits. *Production and Operations Management, 30,* 864-882. https://doi.org/10.1111/poms.13348

Raju, J. S., Sethuraman, R., & Dhar, S. K. (1995). The Introduction and Performance of Store Brands. *Management Science, 41,* 957-978. https://doi.org/10.1287/mnsc.41.6.957

Shang, W., Ha, A. Y., & Tong, S. (2016). Information Sharing in a Supply Chain with a

Common Retailer. *Management Science, 62,* 245-263. https://doi.org/10.1287/mnsc.2014.2127

Shen, B., Dong, C., & Minner, S. (2022). Combating Copycats in the Supply Chain with Permissioned Blockchain Technology. *Production and Operations Management, 31,* 138-154. https://doi.org/10.1111/poms.13456

Tan, M., & Liu, Y. (2018). Game Analysis of Price Competition between Three Echelon Supply Chains. *American Journal of Industrial and Business Management, 8,* 2403-2420. https://doi.org/10.4236/ajibm.2018.812161

Tao, F., Wang, Y., & Zhu, S. (2022). Impact of Blockchain Technology on the Optimal Pricing and Quality Decisions of Platform Supply Chains. *International Journal of Production Research, 61,* 3670-3684. https://doi.org/10.1080/00207543.2022.2050828

Tsunoda, Y., & Zennyo, Y. (2021). Platform Information Transparency and Effects on Third-Party Suppliers and Offline Retailers. *Production and Operations Management, 30,* 4219-4235. https://doi.org/10.1111/poms.13518

Wu, J., & Yu, J. (2022). Blockchain's Impact on Platform Supply Chains: Transaction Cost and Information Transparency Perspectives. *International Journal of Production Research, 61,* 3703-3716. https://doi.org/10.1080/00207543.2022.2027037

Wu, Y., Zhang, X., & Chen, J. (2021). Cooperation of Green R&D in Supply Chain with Downstream Competition. *Computers & Industrial Engineering, 160,* Article ID: 107571. https://doi.org/10.1016/j.cie.2021.107571

Yang, Z., Hu, X., Gurnani, H., & Guan, H. (2018). Multichannel Distribution Strategy: Selling to a Competing Buyer with Limited Supplier Capacity. *Management Science, 64,* 2199-2218. https://doi.org/10.1287/mnsc.2016.2702

Appendix

Proof of calculation in Section 3.1

First, the second derivative of the follower is found, and then the second derivative of (2) about p_2 is solved, and $\frac{\partial^2 \pi_{M_2}^{DN}(p_2)}{\partial^2 p_2} = -2-2\gamma < 0$ is obtained, which shows that there is an optimal solution.

Then, $\frac{\partial \pi_{M_2}^{DN}(p_2)}{\partial p_2} = 0$ and solve p_2, there is $p_2(p_1) = \frac{\Delta c\gamma + \gamma p_1 + \Delta c + 1}{2(1+\gamma)}$, put $p_2(p_1) = \frac{\Delta c\gamma + \gamma p_1 + \Delta c + 1}{2(1+\gamma)}$ into Equation (1) and solve for the second derivative of $\pi_{M_1}^{DN}(p_1)$ with respect to p_1 to get $\frac{\partial^2 \pi_{M_1}^{DN}(p_1)}{\partial^2 p_1} = -2 + 2\gamma\left(\frac{\gamma}{2+2\gamma} - 1\right) < 0$. Then, $\frac{\partial \pi_{M_1}^{DN}(p_1)}{\partial p_1} = 0$, solve p_1, we can get

$p_1^{DN*} = \frac{2\Delta c\gamma^2 + 5\Delta c\gamma + 2\Delta c + 3\gamma + 2}{2(\gamma^2 + 4\gamma + 2)}$, and then

$p_2^{DN*} = \frac{4\Delta c\gamma^3 + (15\Delta c + 5)\gamma^2 + (14\Delta c + 10)\gamma + 4\Delta c + 4}{4(\gamma^2 + 4\gamma + 2)(\gamma + 1)}$, put p_1^{DN*}, p_2^{DN*} into Equations (1) and (2), so we can get the profit optimal solution:

$$\pi_{M_1}^{DN*} = \frac{(\Delta c - 1)^2 (3\gamma + 2)^2}{8(\gamma^2 + 4\gamma + 2)(\gamma + 1)}, \quad \pi_{M_2}^{DN*} = \frac{(\Delta c - 1)^2 (5\gamma^2 + 10\gamma + 4)^2}{16(1+\gamma)(\gamma^2 + 4\gamma + 2)^2}.$$

End of proof.

Proof of calculation in Section 3.2

First, the second derivative of the follower is found, and then the second derivative of (5) about p_2 is solved, and $\frac{\partial^2 \pi_{M_2}^{RN}(p_2)}{\partial^2 p_2} = -2-2\gamma < 0$ is obtained, which shows that there is an optimal solution.

Then, $\frac{\partial \pi_{M_2}^{RN}(p_2)}{\partial p_2} = 0$ and solve p_2, there is $p_2(p_1) = \frac{\Delta c\gamma + \gamma p_1 + \Delta c + 1}{2(1+\gamma)}$, put $p_2(p_1) = \frac{\Delta c\gamma + \gamma p_1 + \Delta c + 1}{2(1+\gamma)}$ into Equation (4) and solve for the second derivative of $\pi_R^{RN}(p_1)$ with respect to p_1 to get $\frac{\partial^2 \pi_R^{RN}(p_1)}{\partial^2 p_1} = -2 + 2\gamma\left(\frac{\gamma}{2+2\gamma} - 1\right) < 0$. Then, $\frac{\partial \pi_R^{RN}(p_1)}{\partial p_1} = 0$, solve p_1, we can get

$p_1(w) = \frac{2\Delta c\gamma^2 + \gamma^2 w + 5\Delta c\gamma + 4\gamma w + 2\Delta c + 3\gamma + 2w + 2}{2(\gamma^2 + 4\gamma + 2)}$, and then

$p_2^{DN*} = \frac{4\Delta c\gamma^3 + (15\Delta c + 5)\gamma^2 + (14\Delta c + 10)\gamma + 4\Delta c + 4}{4(\gamma^2 + 4\gamma + 2)(\gamma + 1)}$, put $p_1(w), p_2(w)$

into Equation (3), solve w^{RN*}, so we can get the profit optimal solution: $w^{RN*}=\frac{\Delta c\gamma^2+\Delta c\gamma+3\gamma+2}{2\left(\gamma^2+4\gamma+2\right)}$. So, it's easy to get

$$p_1^{RN*}=\frac{5\Delta c\gamma^2+\left(11\Delta c+9\right)\gamma+4\Delta c+6}{4\left(\gamma^2+4\gamma+2\right)},$$

$$p_2^{RN*}=\frac{9\Delta c\gamma^3+\left(31\Delta c+13\right)\gamma^2+\left(28\Delta c+22\right)\gamma+8\Delta c+8}{8\left(\gamma^2+4\gamma+2\right)\left(\gamma+1\right)}.$$

Finally, by putting $w^{RN*}, p_1^{RN*}, p_2^{RN*}$ into Formulas (3), (4) and (5), the optimal profit solution can be obtained: $\pi_{M_1}^{RN*}=\frac{\left(\Delta c\gamma^2+\left(7\Delta c-3\right)\gamma+4\Delta c-2\right)^2}{16\left(1+\gamma\right)\left(\gamma^2+4\gamma+2\right)}$,

$$\pi_R^{RN*}=\frac{\left(\Delta c\gamma^2+\left(7\Delta c-3\right)\gamma+4\Delta c-2\right)^2}{32\left(1+\gamma\right)\left(\gamma^2+4\gamma+2\right)},$$

$$\pi_{M_2}^{RN*}=\frac{\left(\Delta c\gamma^3+\left(13-9\Delta c\right)\gamma^2+\left(22-20\Delta c\right)\gamma-8\Delta c+8\right)^2}{64\left(1+\gamma\right)\left(\gamma^2+4\gamma+2\right)^2}.$$

End of proof.

The proof in Section 3.3 is similar to that in Section 3.1. The proof in Section 3.4 is similar to the proof in Section 3.2.

Proof of Proposition 1:

$$\pi_{M_1}^{DN*}-\pi_{M_1}^{RN*}=\frac{\left(-\gamma^4-14\gamma^3-39\gamma^2-32\gamma-8\right)\Delta c^2+\left(6\gamma^3+10\gamma^2+4\gamma\right)\Delta c+9\gamma^2+12\gamma+4}{16\left(\gamma^2+4\gamma+2\right)\left(1+\gamma\right)}$$

The numerator of this fraction is:

$$f\left(\Delta c\right)=\left(-\gamma^4-14\gamma^3-39\gamma^2-32\gamma-8\right)\Delta c^2+\left(6\gamma^3+10\gamma^2+4\gamma\right)\Delta c+9\gamma^2+12\gamma+4$$

Δc is a quadratic function with respect to B that opens downward. $f\left(\Delta c=0\right)=9\gamma^2+12\gamma+4>0$, $f\left(\Delta c=1\right)=-\left(\gamma^2+4\gamma+2\right)<0$. We know that $f\left(\Delta c\right)$ has a root in the range $\Delta c>0$, and $f\left(\Delta c\right)=0$ gives:

$$c_1^*=\frac{3\gamma^3+5\gamma^2+2\gamma-\sqrt{18\gamma^6+168\gamma^5+560\gamma^4+832\gamma^3+616\gamma^2+224\gamma+32}}{\gamma^4+14\gamma^3+39\gamma^2+32\gamma+8}<0,$$

$$c^*=\frac{3\gamma^3+5\gamma^2+2\gamma+\sqrt{18\gamma^6+168\gamma^5+560\gamma^4+832\gamma^3+616\gamma^2+224\gamma+32}}{\gamma^4+14\gamma^3+39\gamma^2+32\gamma+8}>0.$$

So, when $0<\Delta c<c^*$, $\pi_{M_1}^{DN*}>\pi_{M_1}^{RN*}$; when $\Delta c>c^*$, $\pi_{M_1}^{DN*}<\pi_{M_1}^{RN*}$.

End of proof.

Proof of Proposition 3:

$p_1^{DN}-p_2^{DN}=-\frac{\gamma^2\left(\Delta c-1\right)}{4\left(\gamma^2+4\gamma+2\right)\left(1+\gamma\right)}$, it is easy to get: $0<\Delta c<1$, $p_1^{DN}>p_2^{DN}$; $\Delta c>1$, $p_1^{DN}<p_2^{DN}$.

According to $p_1^{DB} - p_2^{DB} = \frac{\left(-\gamma^3 - 7\gamma^2 - 10\gamma - 4\right)\Delta c + \gamma^2}{4\left(\gamma^2 + 4\gamma + 2\right)\left(1+\gamma\right)}$, so $\left(-\gamma^3 - 7\gamma^2 - 10\gamma - 4\right)\Delta c + \gamma^2 = 0$, we can get $\Delta c_1 = \frac{\gamma^2}{\gamma^3 + 7\gamma^2 + 10\gamma + 4}$. It is easy to get when $\Delta c > \Delta c_1 = \frac{\gamma^2}{\gamma^3 + 7\gamma^2 + 10\gamma + 4}$, $p_1^{DB} - p_2^{DB} < 0$. When $0 < \Delta c < \Delta c_1 = \frac{\gamma^2}{\gamma^3 + 7\gamma^2 + 10\gamma + 4}$, $p_1^{DB} > p_2^{DB}$.

End of proof.

Proof of Proposition 4:

$$p_1^{RN*} - p_2^{RN*} = \frac{\Delta c\gamma^3 + \left(\Delta c + 5\right)\gamma^2 + \left(2\Delta c + 8\right)\gamma + 4}{8\left(\gamma^2 + 4\gamma + 2\right)\left(1+\gamma\right)} > 0.$$

According to $p_1^{RB} - p_2^{RB} = \frac{\left(-\gamma^3 - 11\gamma^2 - 18\gamma - 8\right)\Delta c + 5\gamma^2 + 8\gamma + 4}{8\left(\gamma^2 + 4\gamma + 2\right)\left(1+\gamma\right)}$, and then we set the numerator equal to 0, and we get $\Delta c_2 = \frac{5\gamma^2 + 8\gamma + 4}{\gamma^3 + 11\gamma^2 + 18\gamma + 8}$. So, when $0 < \Delta c < \Delta c_2$, $p_1^{RB} > p_2^{RB}$; when $\Delta c > \Delta c_2$, $p_1^{RB} < p_2^{RB}$.

End of proof.

Proof of Proposition 5:

$p_1^{DB*} - p_1^{DN*} = p_1^{RB*} - p_1^{RN*} = -\frac{\Delta c}{2} < 0$,

$p_2^{DB*} - p_2^{DN*} = p_2^{RB*} - p_2^{RN*} = -\frac{\Delta c\gamma}{4\gamma + 4} < 0$. End of proof.

Proof of Proposition 6:

$p_1^{RB} - p_1^{DB} = \frac{2 + \Delta c\gamma^2 + \left(\Delta c + 3\right)\gamma}{4\gamma^2 + 16\gamma + 8} > 0$; $p_2^{RB} - p_2^{DB} = \frac{\gamma\left(2 + \Delta c\gamma^2 + \left(\Delta c + 3\right)\gamma\right)}{8\left(\gamma^2 + 4\gamma + 2\right)\left(1+\gamma\right)} > 0$

$p_1^{RN} - p_1^{DN} = \frac{2 + \Delta c\gamma^2 + \left(\Delta c + 3\right)\gamma}{4\gamma^2 + 16\gamma + 8} > 0$;

$p_2^{RN} - p_2^{DN} = \frac{\gamma\left(2 + \Delta c\gamma^2 + \left(\Delta c + 3\right)\gamma\right)}{8\left(\gamma + 1\right)\left(\gamma^2 + 4\gamma + 2\right)} > 0$. End of proof.

Proof of Proposition 7:

According to $q_1^{DN} - q_2^{DN} = \frac{\gamma^2\left(\Delta c - 1\right)\left(1 + 2\gamma\right)}{4\left(1+\gamma\right)\left(\gamma^2 + 4\gamma + 2\right)}$, so, $0 < \Delta c < 1, q_1^{DN} < q_2^{DN}$; $\Delta c > 1,\ q_1^{DN} > q_2^{DN}$.

According to $q_1^{DB} - q_2^{DB} = \frac{\left(\gamma + 1/2\right)\left(\left(\gamma^3 + 7\gamma^2 + 10\gamma + 4\right)\Delta c - \gamma^2\right)}{2\left(1+\gamma\right)\left(\gamma^2 + 4\gamma + 2\right)}$, and then we set the numerator equal to 0, and we get $\Delta c_3 = \frac{\gamma^2}{\gamma^3 + 7\gamma^2 + 10\gamma + 4}$. So, when $\Delta c > \Delta c_3$, $q_1^{DB} > q_2^{DB}$; $0 < \Delta c < \Delta c_3$, $q_1^{DB} < q_2^{DB}$. End of proof.

Proof of Proposition 8:

$$q_1^{RN}-q_2^{RN}=-\frac{\left(4+\Delta c\gamma^3+(\Delta c+5)\gamma^2+(2\Delta c+8)\gamma\right)(\gamma+1/2)}{4(1+\gamma)\left(\gamma^2+4\gamma+2\right)}<0.$$

According to $q_1^{RB}-q_2^{RB}=\frac{(\gamma+1/2)\left(\left(\gamma^3+11\gamma^2+18\gamma+8\right)\Delta c-5\gamma^2-8\gamma-4\right)}{4(1+\gamma)\left(\gamma^2+4\gamma+2\right)}$,

And then we set the numerator equal to 0, and we get $\Delta c_4=\frac{5\gamma^2+8\gamma+4}{\gamma^3+11\gamma^2+18\gamma+8}$, so,

$\Delta c>\frac{5\gamma^2+8\gamma+4}{\gamma^3+11\gamma^2+18\gamma+8}$, $q_1^{RB}>q_2^{RB}$; $0<\Delta c<\frac{5\gamma^2+8\gamma+4}{\gamma^3+11\gamma^2+18\gamma+8}$, $q_1^{RB}<q_2^{RB}$.

End of proof.

Proof of Proposition 9:

$$q_1^{RB}-q_1^{DB}=q_1^{RN}-q_1^{DN}=\frac{-2-\Delta c\gamma^2+(-\Delta c-3)\gamma}{8\gamma+8}<0;$$

$$q_2^{RB}-q_2^{DB}=q_2^{RN}-q_2^{DN}=\frac{\left(2+\Delta c\gamma^2+(c+3)\gamma\right)\gamma}{8\gamma^2+32\gamma+16}>0.$$

End of proof.

Proof of Proposition 10:

According to $\pi_{M_1}^{DB}-\pi_{M_1}^{DN}=\frac{\left(\left(\gamma^2-2\gamma-2\right)\Delta c+6\gamma+4\right)\Delta c}{8\gamma+8}$,

$\left(\gamma^2-2\gamma-2\right)\Delta c+6\gamma+4=0$, so $\Delta c_5=-\frac{2(3\gamma+2)}{\gamma^2-2\gamma-2}$, then, when $0<\Delta c<-\frac{2(3\gamma+2)}{\gamma^2-2\gamma-2}$, $\pi_{M_1}^{DB}>\pi_{M_1}^{DN}$. When $\Delta c>-\frac{2(3\gamma+2)}{\gamma^2-2\gamma-2}$, $\pi_{M_1}^{DB}<\pi_{M_1}^{DN}$.

According to $\pi_{M_2}^{DB}-\pi_{M_2}^{DN}=\frac{\left(\left(\gamma^3+14\gamma^2+22\gamma+8\right)\Delta c-10\gamma^2-20\gamma-8\right)\gamma\Delta c}{16\left(\gamma^2+4\gamma+2\right)^2(1+\gamma)}$,

$\left(\gamma^3+14\gamma^2+22\gamma+8\right)\Delta c-10\gamma^2-20\gamma-8=0$, so there are $\Delta c_6=\frac{10\gamma^2+20\gamma+8}{\gamma^3+14\gamma^2+22\gamma+8}$. When $0<\Delta c<\frac{2\left(5\gamma^2+10\gamma+4\right)}{\gamma^3+14\gamma^2+22\gamma+8}$, $\pi_{M_2}^{DB}<\pi_{M_2}^{DN}$; when $\Delta c>\frac{2\left(5\gamma^2+10\gamma+4\right)}{\gamma^3+14\gamma^2+22\gamma+8}$, $\pi_{M_2}^{DB}>\pi_{M_2}^{DN}$.

End of proof.

Proof of Proposition 11:

According to $\pi_{M_1}^{RB}-\pi_{M_1}^{RN}=-\frac{(\Delta c-1)\Delta c(3\gamma+2)}{4\gamma+4}$, then $0<\Delta c<1$, $\pi_{M_1}^{RB}>\pi_{M_1}^{RN}$; $\Delta c>1$, $\pi_{M_1}^{RB}<\pi_{M_1}^{RN}$.

According to $\pi_R^{RB}-\pi_R^{RN}=-\frac{(\Delta c-1)\Delta c(3\gamma+2)}{8\gamma+8}$, then $0<\Delta c<1$, $\pi_R^{RB}>\pi_R^{RN}$; $\Delta c>1$, $\pi_R^{RB}<\pi_R^{RN}$.

According to $\pi_{M_2}^{RB} - \pi_{M_2}^{RN} = \frac{\left(13\gamma^2 + 22\gamma + 8\right)\left(\Delta c - 1\right)\gamma\Delta c}{16\left(\gamma^2 + 4\gamma + 2\right)\left(1+\gamma\right)}$,

then $0 < \Delta c < 1$, $\pi_{M_2}^{RB} < \pi_{M_2}^{RN}$; $\Delta c > 1$, $\pi_{M_2}^{RB} > \pi_{M_2}^{RN}$.

End of proof.

Proof of Proposition 12:

$$\pi_{M_2}^{RB+*} - \pi_{M_2}^{DB+*} = \frac{-\Delta c^2\gamma^2 + \left(\gamma^2 - \gamma\right)\Delta c + \left(4F + 4T + 1\right)\gamma + 4F + 4T}{8 + 8\gamma}.$$

when $0 < \Delta c < \Delta c_{B+}$, $\pi_{M_2}^{RB+*} - \pi_{M_2}^{DB+*} > 0$, Distribution channel alliance is an advantageous strategy for alternative manufacturers; when $\Delta c > \Delta c_{B+}$, $\pi_{M_2}^{RB+*} - \pi_{M_2}^{DB+*} < 0$, Direct channel alliance is an advantageous strategy for alternative manufacturers.

$$\Delta c_{B+} = \frac{\gamma^2 - \gamma + \sqrt{16F\gamma^3 + \gamma^4 + 16\gamma^3 T + 16F\gamma^2 + 2\gamma^3 + 16\gamma^2 T + \gamma^2}}{2\gamma^2}.$$

End of proof.

Proof of Proposition 13:

$$\pi_{SC}^{DB+} - \pi_{SC}^{DB} = \frac{\begin{array}{l}\left(\gamma^6 + 10\gamma^5 + 21\gamma^4 + 16\gamma^3 + 4\gamma^2\right)\Delta c^2 + \left(-10\gamma^5 - 30\gamma^4 - 28\gamma^3 - 8\gamma^2\right)\Delta c \\ +\left(-16F - 16T + 8\right)\gamma^5 + \left(-144F - 144T + 29\right)\gamma^4 + \left(-448F - 448T + 28\right)\gamma^3 \\ +\left(-576F - 576T + 8\right)\gamma^2 + \left(-320F - 320T\right)\gamma - 64F - 64T\end{array}}{16\left(\gamma^2 + 4\gamma + 2\right)^2\left(1+\gamma\right)}$$

$$\begin{aligned} f\left(\Delta c\right) = {} & \left(\gamma^6 + 10\gamma^5 + 21\gamma^4 + 16\gamma^3 + 4\gamma^2\right)\Delta c^2 + \left(-10\gamma^5 - 30\gamma^4 - 28\gamma^3 - 8\gamma^2\right)\Delta c \\ & + \left(-16F - 16T + 8\right)\gamma^5 + \left(-144F - 144T + 29\right)\gamma^4 + \left(-448F - 448T + 28\right)\gamma^3 \\ & + \left(-576F - 576T + 8\right)\gamma^2 + \left(-320F - 320T\right)\gamma - 64F - 64T \end{aligned}$$

is a quadratic function of Δc. And $f\left(\Delta c\right)$ is a quadratic function with an opening up. And $f\left(\Delta c = 0\right) < 0$, $f\left(\Delta c = 1\right) < 0$. So, according to $f\left(\Delta c\right) = 0$, then:

$$\Delta c_7 = \frac{5\gamma^5 + 15\gamma^4 + 14\gamma^3 + 4\gamma^2 + 2\sqrt{\begin{array}{l}4F\gamma^{11} + 4\gamma^{11}T + 76F\gamma^{10} - 2\gamma^{11} + 76\gamma^{10}T + 556F\gamma^9 - 21\gamma^{10} \\ +556\gamma^9 T + 2084F\gamma^8 - 84\gamma^9 + 2084\gamma^8 T + 4464F\gamma^7 - 165\gamma^8 \\ +4464\gamma^7 T + 5776F\gamma^6 - 176\gamma^7 + 5776\gamma^6 T + 4592F\gamma^5 - 104\gamma^6 \\ +4592\gamma^5 T + 2192F\gamma^4 - 32\gamma^5 + 2192\gamma^4 T + 576F\gamma^3 - 4\gamma^4 \\ +576\gamma^3 T + 64F\gamma^2 + 64\gamma^2 T\end{array}}}{\gamma^2\left(\gamma^4 + 10\gamma^3 + 21\gamma^2 + 16\gamma + 4\right)}$$

$$\Delta c_7^{+} = \frac{5\gamma^5 + 15\gamma^4 + 14\gamma^3 + 4\gamma^2 - 2\sqrt{\begin{array}{l}4F\gamma^{11} + 4\gamma^{11}T + 76F\gamma^{10} - 2\gamma^{11} + 76\gamma^{10}T + 556F\gamma^9 - 21\gamma^{10} \\ +556\gamma^9 T + 2084F\gamma^8 - 84\gamma^9 + 2084\gamma^8 T + 4464F\gamma^7 - 165\gamma^8 \\ +4464\gamma^7 T + 5776F\gamma^6 - 176\gamma^7 + 5776\gamma^6 T + 4592F\gamma^5 - 104\gamma^6 \\ +4592\gamma^5 T + 2192F\gamma^4 - 32\gamma^5 + 2192\gamma^4 T + 576F\gamma^3 - 4\gamma^4 \\ +576\gamma^3 T + 64F\gamma^2 + 64\gamma^2 T\end{array}}}{\gamma^2\left(\gamma^4 + 10\gamma^3 + 21\gamma^2 + 16\gamma + 4\right)}$$

It can be seen through analysis, $\Delta c_7^+ < 0 < \Delta c_7$, $\Delta c > 0$, so truncation Δc_7^+. So, when $0 < \Delta c < \Delta c_7$, $f(\Delta c) < 0$, i.e. $\pi_{SC}^{DB+} < \pi_{SC}^{DB}$. When $\Delta c > \Delta c_7$, $f(\Delta c) > 0$, i.e. $\pi_{SC}^{DB+} > \pi_{SC}^{DB}$. End of proof.

Proof of Proposition 14:

$$\pi_{SC}^{RB+} - \pi_{SC}^{RB} = \frac{\begin{array}{l}\left(5\gamma^6 + 58\gamma^5 + 109\gamma^4 + 80\gamma^3 + 20\gamma^2\right)\Delta c^2 + \left(-50\gamma^5 - 70\gamma^4 - 4\gamma^3 + 40\gamma^2 + 16\gamma\right)\Delta c \\ +\left(-64F - 64T + 32\right)\gamma^5 + \left(-576F - 576T + 61\right)\gamma^4 + \left(-1792F - 1792T + 4\right)\gamma^3 \\ +\left(-2304F - 2304T - 40\right)\gamma^2 + \left(-1280F - 1280T - 16\right)\gamma - 256F - 256T\end{array}}{64\left(\gamma^2 + 4\gamma + 2\right)^2 (1+\gamma)}$$

$$\begin{aligned} f^{\Delta}(\Delta c) = {} & \left(5\gamma^6 + 58\gamma^5 + 109\gamma^4 + 80\gamma^3 + 20\gamma^2\right)\Delta c^2 + \left(-50\gamma^5 - 70\gamma^4 - 4\gamma^3 + 40\gamma^2 + 16\gamma\right)\Delta c \\ & +\left(-64F - 64T + 32\right)\gamma^5 + \left(-576F - 576T + 61\right)\gamma^4 + \left(-1792F - 1792T + 4\right)\gamma^3 \\ & +\left(-2304F - 2304T - 40\right)\gamma^2 + \left(-1280F - 1280T - 16\right)\gamma - 256F - 256T \end{aligned}$$

is a quadratic function of Δc. And $f^{\Delta}(\Delta c)$ is a quadratic function with an opening up. And $f^{\Delta}(\Delta c = 0) < 0$, $f^{\Delta}(\Delta c = 1) < 0$. So, according to $f^{\Delta}(\Delta c) = 0$, there are:

$$\Delta c_8 = \frac{25\gamma^5 + 35\gamma^4 + 2\gamma^3 - 20\gamma^2 - 8\gamma + 2\sqrt{\begin{array}{l}80F\gamma^{11} + 80\gamma^{11}T + 1648F\gamma^{10} - 40\gamma^{11} + 1648\gamma^{10}T + 12336F\gamma^9 \\ -384\gamma^{10} + 12336\gamma^9 T + 45840F\gamma^8 - 1324\gamma^9 + 45840\gamma^8 T \\ +95680F\gamma^7 - 1979\gamma^8 + 95680\gamma^7 T + 120384F\gamma^6 - 1104\gamma^7 \\ +120384\gamma^6 T + 93632F\gamma^5 + 488\gamma^6 + 93632\gamma^5 T + 44096F\gamma^4 \\ +1056\gamma^5 + 44096\gamma^4 T + 11520F\gamma^3 + 612\gamma^4 + 11520\gamma^3 T \\ +1280F\gamma^2 + 160\gamma^3 + 1280\gamma^2 T + 16\gamma^2\end{array}}}{\gamma^2\left(5\gamma^4 + 58\gamma^3 + 109\gamma^2 + 80\gamma + 20\right)}$$

$$\Delta c_8^+ = \frac{25\gamma^5 + 35\gamma^4 + 2\gamma^3 - 20\gamma^2 - 8\gamma - 2\sqrt{\begin{array}{l}80F\gamma^{11} + 80\gamma^{11}T + 1648F\gamma^{10} - 40\gamma^{11} + 1648\gamma^{10}T + 12336F\gamma^9 \\ -384\gamma^{10} + 12336\gamma^9 T + 45840F\gamma^8 - 1324\gamma^9 + 45840\gamma^8 T \\ +95680F\gamma^7 - 1979\gamma^8 + 95680\gamma^7 T + 120384F\gamma^6 - 1104\gamma^7 \\ +120384\gamma^6 T + 93632F\gamma^5 + 488\gamma^6 + 93632\gamma^5 T + 44096F\gamma^4 \\ +1056\gamma^5 + 44096\gamma^4 T + 11520F\gamma^3 + 612\gamma^4 + 11520\gamma^3 T \\ +1280F\gamma^2 + 160\gamma^3 + 1280\gamma^2 T + 16\gamma^2\end{array}}}{\gamma^2\left(5\gamma^4 + 58\gamma^3 + 109\gamma^2 + 80\gamma + 20\right)}$$

so, $\Delta c_8^+ < 0 < \Delta c_8$, $\Delta c > 0$, so truncation Δc_8^+. When $0 < \Delta c < \Delta c_8$, $f(\Delta c) < 0$, i.e. $\pi_{SC}^{RB+} < \pi_{SC}^{RB}$. when $\Delta c > \Delta c_8$, $f(\Delta c) < 0$, i.e. $\pi_{SC}^{RB+} > \pi_{SC}^{RB}$. End of proof.

Expressions for the RN+ and DN+ models in Section 6.1

DN+

$Max_{(p_1,p_2)}\pi_{SC}^{DN+} = (p_1 - \Delta c)q_1 + (p_2 - \Delta c)q_2$, it is easy to get the optimal profit solution as: $\pi_{M_1}^{DN+*} = \frac{(\Delta c - 1)^2}{4}$, $\pi_{M_2}^{DN+*} = \frac{(\Delta c - 1)^2}{4}$.

RN+

$\pi_{M_1}^{RN+}(w) = (w - \Delta c)q_1$, $Max_{(p_1,p_2)}\pi_{R+M_2}^{RN+} = (p_1 - w - \Delta c)q_1 + (p_2 - \Delta c)q_2$, it is easy to get the optimal profit solution as:

$$\pi_{M_1}^{RN+*}=\frac{\left(-1+(\gamma+2)\Delta c\right)^2}{8+8\gamma},\quad \pi_{M_2}^{RN+*}=-\frac{\left(\Delta c\gamma^2+(-2\Delta c+3)\gamma-2\Delta c+2\right)(\Delta c-1)}{8+8\lambda},$$

$$\pi_R^{RN+*}=\frac{(3\Delta c\gamma+2\Delta c-2\gamma-1)(\Delta c\gamma+2\Delta c-1)}{16+16\gamma}.$$

Section 6.2: Proof of the existence condition of stable points in evolutionary games:

Proof of stability judgment of equilibrium point (0, 0):

$$\pi_{M_1}^{RB+*}-\pi_{M_1}^{RN+*}=\frac{(-2F-2T)\lambda-\Delta c^2+\Delta c}{2},$$

when $y_1^*<\Delta c<y_2^*$, $\pi_{M_1}^{RB+*}-\pi_{M_1}^{RN+*}>0$.
when $0<\Delta c<y_1^*$ & $\Delta c>y_2^*$, $\pi_{M_1}^{RB+*}-\pi_{M_1}^{RN+*}<0$.

$$y_1^*=\frac{1-\sqrt{-8\lambda F-8\lambda T+1}}{2},\quad y_2^*=\frac{1+\sqrt{-8\lambda F-8\lambda T+1}}{2},$$

$$\pi_{M_2}^{DN+*}-\pi_{M_2}^{RN+*}=\frac{(\Delta c-1)(\Delta c\gamma+1)}{8+8\gamma},$$

when $0<\Delta c<1$, $\pi_{M_2}^{DN+*}-\pi_{M_2}^{RN+*}<0$; when $\Delta c>1$, $\pi_{M_2}^{DN+*}-\pi_{M_2}^{RN+*}>0$;

$$\left(\pi_{M_1}^{RB+*}-\pi_{M_1}^{RN+*}\right)+\left(\pi_{M_2}^{DN+*}-\pi_{M_2}^{RN+*}\right)=\frac{\left(-\gamma^2+2\gamma+2\right)\Delta c^2+\left(-\gamma^2-7\gamma-4\right)\Delta c+(8F+8T+1)\gamma+8F+8T}{8+8\gamma}$$

, is a quadratic function of Δc. And $f(\Delta c)$ is a quadratic function with an opening up. After analysis, it is found that there are two positive roots under the precondition of $\Delta c>0$:

$$y_4^*=\frac{\gamma^2-5\gamma-4-\sqrt{1+\gamma}\sqrt{32\left(\gamma^2-4\gamma-4\right)(F+T)\lambda+(1+\gamma)(\gamma-4)^2}}{2\gamma^2-8\gamma-8},$$

$$y_5^*=\frac{\gamma^2-5\gamma-4+\sqrt{1+\gamma}\sqrt{32\left(\gamma^2-4\gamma-4\right)(F+T)\lambda+(1+\gamma)(\gamma-4)^2}}{2\gamma^2-8\gamma-8}.$$ So,

$$y_4^*<\Delta c<y_5^*,\ \left(\pi_{M_1}^{RB+*}-\pi_{M_1}^{RN+*}\right)+\left(\pi_{M_2}^{DN+*}-\pi_{M_2}^{RN+*}\right)<0;$$

$$0<\Delta c<y_4^*,\ \Delta c>y_5^*,\ \left(\pi_{M_1}^{RB+*}-\pi_{M_1}^{RN+*}\right)+\left(\pi_{M_2}^{DN+*}-\pi_{M_2}^{RN+*}\right)>0.$$

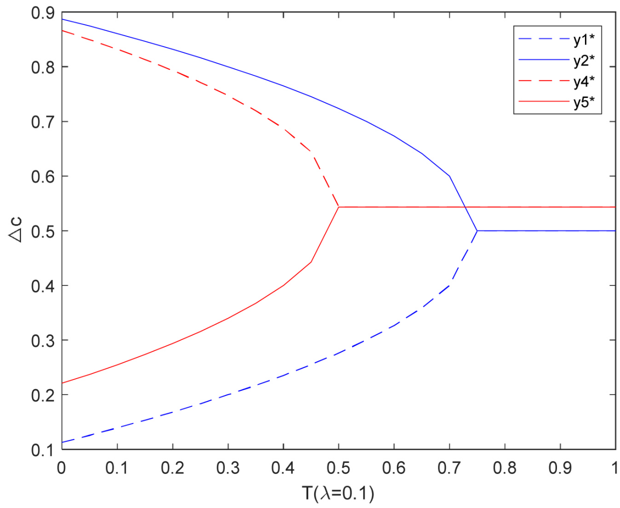
After analysis, as shown in the figure, the threshold set satisfying $Det>0$, $Tr<0$ does not have intersection, so (0, 0) is the unstable point. (The parameter of the threshold range is assigned to "$\gamma=0.5$, $F=0.5$, $\lambda=0.1$ & 0.2").

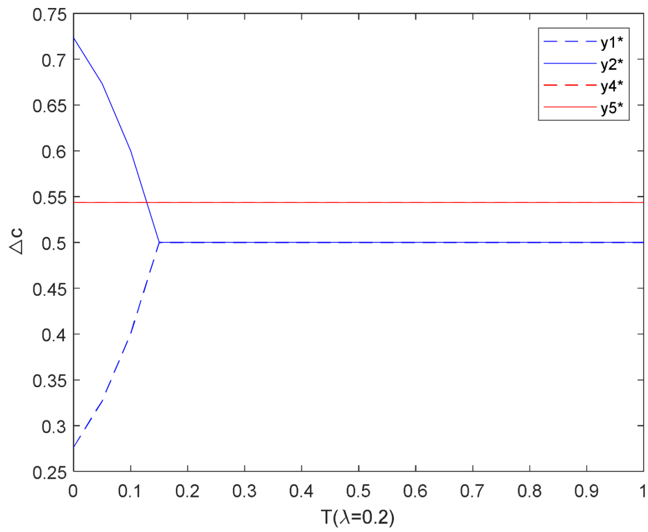
End of proof.

Proof of stability judgment of equilibrium point (0, 1):

$$\pi_{M_1}^{DB+*}-\pi_{M_1}^{DN+*}=\frac{-\Delta c^2+(2+\gamma)\Delta c-2F-2T}{4}$$

$$0<\Delta c<y_1,\ \Delta c>y_2,\ \pi_{M_1}^{DB+*}-\pi_{M_1}^{DN+*}<0.$$





$$-\left(\pi_{M_2}^{DN+*}-\pi_{M_2}^{RN+*}\right)=\frac{(\Delta c-1)\gamma(\Delta c\gamma+1)}{8\gamma+8}$$

$$\Delta c>1,\ -\left(\pi_{M_2}^{DN+*}-\pi_{M_2}^{RN+*}\right)<0$$

By analyzing Det & Tr at the equilibrium point (0, 1), we get: when $\Delta c>1$, $1<\Delta c<y_1 \cup \Delta c>y_2$, $Det>0$ & $Tr<0$, (0, 1) is a stable point. $y_1=\dfrac{2+\gamma-\sqrt{\gamma^2-8F+4\gamma-8T+4}}{2}$, $y_2=\dfrac{2+\gamma+\sqrt{\gamma^2-8F+4\gamma-8T+4}}{2}$.

End of proof.

Proof of stability judgment of equilibrium point (1, 0):

$$-\left[\pi_{M_1}^{RB+*}-\pi_{M_1}^{RN+*}\right]$$
$$=\frac{\left(-\gamma^2+12\gamma+8\right)\Delta c^2+(-22\gamma-12)\Delta c+\left(8+(16F+16T)\lambda\right)\gamma+3+(16F+16T)\lambda}{16\gamma+16}$$

Analyze the positive and negative of $-\left[\pi_{M_1}^{RB+*}-\pi_{M_1}^{RN+*}\right]$. The proof is similar to the proof for (1, 1).

When $y_1' < \Delta c < y_2'$, $-\left[\pi_{M_1}^{RB+*} - \pi_{M_1}^{RN+*}\right] < 0$.

When $0 < \Delta c < y_1'$ & $\Delta c > y_2'$, $-\left[\pi_{M_1}^{RB+*} - \pi_{M_1}^{RN+*}\right] > 0$.

$$y_1' = \frac{1 - \sqrt{-8\lambda F - 8\lambda T + 1}}{2}, \quad y_2' = \frac{1 + \sqrt{-8\lambda F - 8\lambda T + 1}}{2}$$

$$\pi_{M_2}^{DB+*} - \pi_{M_2}^{RB+*} = \frac{\gamma^2 \Delta c^2 + \left(-\gamma^2 + \gamma\right)\Delta c + \left(-4F - 4T - 1\right)\gamma - 4F - 4T}{8 + 8\gamma}$$

Analyze the positive and negative of $\pi_{M_2}^{DB+*} - \pi_{M_2}^{RB+*}$. The proof is similar to the proof for (1, 1).

When $0 < \Delta c < y_3'$, $\pi_{M_2}^{DB+*} - \pi_{M_2}^{RB+*} < 0$.

When $\Delta c > y_3'$, $\pi_{M_2}^{DB+*} - \pi_{M_2}^{RB+*} > 0$.

$$y_3' = \frac{\gamma^2 - \gamma + \sqrt{16F\gamma^3 + \gamma^4 + 16\gamma^3 T + 16F\gamma^2 + 2\gamma^3 + 16\gamma^2 T + \gamma^2}}{2\gamma^2}$$

$$-\left[\pi_{M_1}^{RB+*} - \pi_{M_1}^{RN+*}\right] + \left(\pi_{M_2}^{DB+*} - \pi_{M_2}^{RB+*}\right)$$
$$= \frac{\left(\gamma^2 + 4\gamma + 4\right)\Delta c^2 + \left(-\gamma^3 - 3\gamma - 4\right)\Delta c + \left(\left(8F + 8T\right)\lambda - 4F - 4T - 1\right)\gamma + 8\left(F + T\right)\left(\lambda - \frac{1}{2}\right)}{8 + 8\gamma}$$

And $f'(\Delta c)$ is a quadratic function with an opening up. After analysis, it is found that there are two positive roots, so:

when $\lambda > \frac{1}{2}$, $0 < \Delta c < y_4'$, $\Delta c > y_5'$, $-\left[\pi_{M_1}^{RB+*} - \pi_{M_1}^{RN+*}\right] + \left(\pi_{M_2}^{DB+*} - \pi_{M_2}^{RB+*}\right) > 0$;

$y_4' < \Delta c < y_5'$, $-\left[\pi_{M_1}^{RB+*} - \pi_{M_1}^{RN+*}\right] + \left(\pi_{M_2}^{DB+*} - \pi_{M_2}^{RB+*}\right) < 0$;

when $0 < \lambda < \frac{1}{2}$, $0 < \Delta c < y_5'$, $-\left[\pi_{M_1}^{RB+*} - \pi_{M_1}^{RN+*}\right] + \left(\pi_{M_2}^{DB+*} - \pi_{M_2}^{RB+*}\right) < 0$;

$\Delta c > y_5'$, $-\left[\pi_{M_1}^{RB+*} - \pi_{M_1}^{RN+*}\right] + \left(\pi_{M_2}^{DB+*} - \pi_{M_2}^{RB+*}\right) > 0$.

$$y_4' = \frac{\gamma^2 + 3\gamma + 4 - \sqrt{1+\gamma}\sqrt{-32\left(\gamma+2\right)^2\left(\lambda - 1/2\right)F - 32\left(\gamma+2\right)^2\left(\lambda - 1/2\right)T + \left(1+\gamma\right)\left(\gamma+4\right)^2}}{2\left(\gamma+2\right)^2}$$

$$y_5' = \frac{\gamma^2 + 3\gamma + 4 + \sqrt{1+\gamma}\sqrt{-32\left(\gamma+2\right)^2\left(\lambda - 1/2\right)F - 32\left(\gamma+2\right)^2\left(\lambda - 1/2\right)T + \left(1+\gamma\right)\left(\gamma+4\right)^2}}{2\left(\gamma+2\right)^2}$$

By analyzing Det & Tr at the equilibrium point (1, 0), we get:

when $0 < \lambda < \frac{1}{2}$, and when $y_1' < \Delta c < y_2'$, $det > 0$, $tr < 0$, (1, 0) is a stable point.

End of proof.

Proof of stability judgment of equilibrium point (1, 1):

$$-\left(\pi_{M_1}^{DB+*} - \pi_{M_1}^{DN+*}\right) = \frac{\Delta c^2 + \left(-\gamma - 2\right)\Delta c + 2F + 2T}{4}$$

Analyze the positive and negative of $-\left(\pi_{M_1}^{DB+*} - \pi_{M_1}^{DN+*}\right)$. The numerator is a quadratic function with respect to the opening up of Δc.

$f''(\Delta c)=\Delta c^2+(-\gamma-2)\Delta c+2F+2T$, According to $f''(\Delta c)=0$:

$$y_1''=\frac{2+\gamma-\sqrt{\gamma^2-8F+4\gamma-8T+4}}{2},\quad y_2''=\frac{2+\gamma+\sqrt{\gamma^2-8F+4\gamma-8T+4}}{2}$$

($y_1''<y_2''$), and $f''(\Delta c=0)>0$, $f''(\Delta c=1)>0$, so, $0<y_1''<y_2''$. $f''(\Delta c)$ has two positive roots in the $\Delta c>0$ range.

When $y_1''<\Delta c<y_2''$, $f''(\Delta c)<0$, $-\left(\pi_{M_1}^{DB+*}-\pi_{M_1}^{DN+*}\right)<0$.

When $0<\Delta c<y_1''$ & $\Delta c>y_2''$, $f''(\Delta c)>0$, $-\left(\pi_{M_1}^{DB+*}-\pi_{M_1}^{DN+*}\right)>0$.

$$-\left(\pi_{M_2}^{DB+*}-\pi_{M_2}^{RB+*}\right)=\frac{-\gamma^2\Delta c^2+\left(\gamma^2-\gamma\right)\Delta c+(4F+4t+1)\gamma+4F+4T}{8+8\gamma}$$

Analyze the positive and negative of $-\left(\pi_{M_2}^{DB+*}-\pi_{M_2}^{RB+*}\right)$. The numerator is a quadratic function with respect to the opening down of Δc.

$f''(\Delta c)=-\gamma^2\Delta c^2+\left(\gamma^2-\gamma\right)\Delta c+(4F+4t+1)\gamma+4F+4T$, according to $f''(\Delta c)=0$:

$$y_3^*=\frac{\gamma^2-\gamma-\sqrt{16F\gamma^3+\gamma^4+16\gamma^3T+16\gamma^2F+2\gamma^3+16\gamma^2T+\gamma^2}}{2\gamma^2}<0$$ (Drop this root.)

$$y_3''=\frac{\gamma^2-\gamma+\sqrt{16F\gamma^3+\gamma^4+16\gamma^3T+16\gamma^2F+2\gamma^3+16\gamma^2T+\gamma^2}}{2\gamma^2}$$

And $f''(\Delta c=0)>0$, $f''(\Delta c=1)>0$, $f''(\Delta c)$ has only one positive roots y_3'' in the $\Delta c>0$ range.

When $0<\Delta c<y_3''$, $f''(\Delta c)>0$, $-\left(\pi_{M_2}^{DB+*}-\pi_{M_2}^{RB+*}\right)>0$.

When $\Delta c>y_3''$, $f''(\Delta c)<0$, $-\left(\pi_{M_2}^{DB+*}-\pi_{M_2}^{RB+*}\right)<0$.

$$-\left(\pi_{M_1}^{DB+*}-\pi_{M_1}^{DN+*}\right)+\left[-\left(\pi_{M_2}^{DB+*}-\pi_{M_2}^{RB+*}\right)\right]$$
$$=\frac{\left(-\gamma^2+2\gamma+2\right)\Delta c^2+\left(-\gamma^2-7\gamma-4\right)\Delta c+(8F+8T+1)\gamma+8F+8T}{8+8\gamma}$$, the numerator is a quadratic function with respect to the opening up of Δc, there are two effective positive roots y_4'', y_5'', which can be seen by analysis:

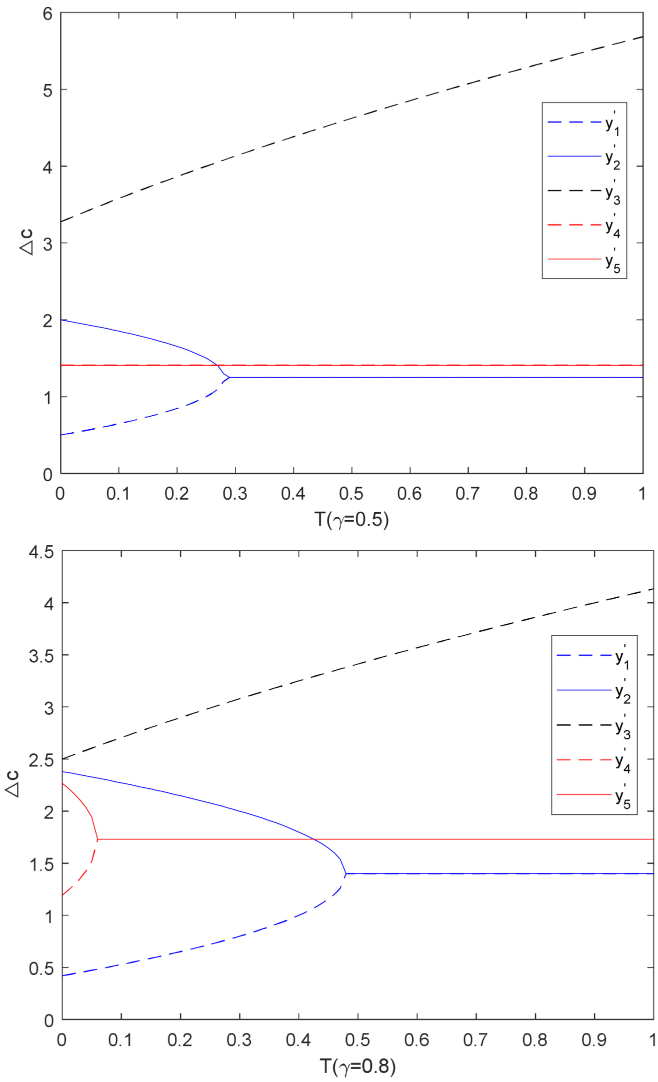
$$y_4''<\Delta c<y_5'',\quad -\left(\pi_{M_1}^{DB+*}-\pi_{M_1}^{DN+*}\right)+\left[-\left(\pi_{M_2}^{DB+*}-\pi_{M_2}^{RB+*}\right)\right]<0;$$

$$0<\Delta c<y_4'',\ \Delta c>y_5'',\quad -\left(\pi_{M_1}^{DB+*}-\pi_{M_1}^{DN+*}\right)+\left[-\left(\pi_{M_2}^{DB+*}-\pi_{M_2}^{RB+*}\right)\right]>0.$$

$$y_4''=\frac{-\gamma^2+\sqrt{\gamma+1}\sqrt{\gamma^3+(32F+32T+17)\gamma^2+(-64F-64t+32)\gamma-64F-64T+16}-7\gamma-4}{2\gamma^2-4\gamma-4}$$

$$y_5''=\frac{-\gamma^2-\sqrt{\gamma+1}\sqrt{\gamma^3+(32F+32T+17)\gamma^2+(-64F-64t+32)\gamma-64F-64T+16}-7\gamma-4}{2\gamma^2-4\gamma-4}$$

Therefore, by analyzing Det & Tr of the equilibrium point (1, 1), as shown in the figure, it is found that there is no threshold intersection that simultaneously meets $Det>0$, $Tr<0$, so the analysis results that (1, 1) is not a stable point.



End of proof.