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Market Data－Driven Demand Forecasting and Inventory Coordination Mechanisms in Retail Supply Chains

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Abstract: With the rapid increase in global data volume and intensified market demand fluctuations, retail supply chains urgently need to improve inventory coordination efficiency through market data-driven demand forecasting. This study focuses on the dual channel supply chain of direct sales (manufacturer+traditional retailer) and distribution (manufacturer+traditional retailer+electronic retailer). Based on the two-stage characteristics of big data technology, a demand forecasting formation mechanism is constructed. The Bayesian Zuckerberg game model and reverse induction method are used to analyze the optimal decisions and expected profits in four information sharing states, and explore the equilibrium strategy of bidirectional information sharing; Incorporate manufacturer product quality improvement and information leakage behavior into the distributed structure, divide into five information states, and study wholesale price, quality improvement investment, and order quantity decisions. Research has found that in direct sales supply chains, traditional retailers are unable to obtain value-added benefits through reverse sharing, and information equilibrium only exists in the cases of forward sharing and no sharing. The intensity of competition affects manufacturers' willingness to share information; In a distributed supply chain, manufacturer decisions are driven by the level of product quality improvement technology and the motivation for information leakage. Information leakage behavior depends on the accuracy of shared channel information - competitive channels tend to leak when their technology is low to enhance their competitiveness, and avoid leakage when the technology is mature. The downstream implementation of information symmetry requires manufacturers to ensure information security and both channels to recognize the consumer stimulus effect of quality improvement; If information is leaked, retailers will only follow up on sharing when consumers highly value product quality. The research has expanded the theory of dual channel supply chain operation management, filled the gap in research on bidirectional sharing and leakage under asymmetric information, provided management insights for enterprises to formulate information sharing strategies and avoid leakage risks, and helped supply chain lean manufacturing and agile production.

1 Introduction

In the retail supply chain, with the development of the Internet and information technology, the global data volume will grow by more than 50 times from 2010 to 2020 and maintain an average annual growth rate of 15%. It is expected to reach 175ZB in 2025, and data will become an emerging resource to promote value creation. Under the commercial digitalization, the enterprise's data storage volume has risen from TB level to PB level, and precision marketing, supply chain management and other applications have been achieved through data mining, machine learning and other technologies. However, the market demand volatility has intensified (for example, 36% of consumers have adjusted the purchase of necessities/non necessities due to COVID-19), and the traditional subjective experience prediction accuracy is insufficient. Enterprises need to use big data technology to improve the accuracy of demand prediction to avoid the risk of shortage and inventory backlog. The popularization of mobile terminals has promoted the development of e-commerce, with 812 million Chinese netizens participating in online shopping (accounting for 80.3%). In 2020, online sales reached 10.08 trillion Chinese yuan (accounting for 21.9% of social media). Many enterprises adopt a dual channel supply chain structure[1], but there is an issue of information asymmetry - existing literature mostly focuses on dual channel product pricing and channel selection, with limited research on heterogeneous demand information sharing under big data technology, and more attention paid to one-way sharing from downstream to upstream, ignoring the risks of two-way sharing and information leakage.This study focuses on the dual channel supply chain of direct sales (manufacturer+traditional retailer) and distribution (manufacturer+traditional retailer+electronic retailer), and constructs a demand forecasting formation mechanism based on two-stage features collected and processed by big data technology. Using Bayesian Stackelberg game model[2] and reverse induction method, the optimal decisions and expected profits in four information sharing states are analyzed, and the bidirectional information sharing equilibrium strategy between manufacturers and retailers is explored; Incorporating manufacturer product quality improvement and information leakage behavior into a distributed structure, dividing into five information states, studying wholesale price, quality improvement investment, and order quantity decisions, and revealing the impact of information leakage motivation on vertical sharing motivation.In terms of theoretical contribution, it has expanded the theory of dual channel supply chain operation management and filled the gap in research on bidirectional sharing and information leakage under asymmetric information; The practical significance lies in providing management insights for enterprises to develop information sharing strategies and avoid information leakage risks in uncertain market environments, and helping supply chain lean manufacturing and agile production. The research adopts the literature research method to sort out the achievements in the fields of dual channel supply chain and demand information sharing. The model analysis method is used to construct the profit function and solve the optimal strategy. The MAPLE software is used for numerical simulation and sensitivity analysis. The innovation points include: reconstructing the composition and accuracy analysis of demand forecasting information based on the two-stage characteristics of big data, pioneering a direct sales dual channel two-way sharing research framework, and revealing the impact mechanism of manufacturer information leakage behavior on vertical sharing decisions. The key issues to be addressed include the formulation of information sharing strategies under differentiated big data technology, the impact of information leakage risks on sharing enthusiasm, and the mechanism of big data technology investment on supply chain members' decision-making and expected profits, forming a complete research loop of "market data-driven demand forecasting inventory coordination mechanism", which has significant value for enhancing the resilience of retail supply chains and optimizing inventory management.

2 Correlation theory

2.1A review of research on dual channel supply chain operation

In recent years, with the development of Internet technology and e-commerce, enterprises have become a research hotspot by introducing online channels to form a dual channel supply chain operation model. In the direct sales dual channel structure, manufacturers or retailers operate their own online direct sales channels, and related research focuses on channel selection strategies, pricing and operation strategies, and coordination issues among members. A study has found through model analysis that manufacturers introducing direct sales channels can stimulate traditional retailers' sales efforts, and even if the sales volume of direct sales channels is low, it can still increase manufacturers' profits; Another study suggests that under the influence of strong retailers, if consumers have a low acceptance of direct sales channels, the dual channel model may be detrimental to manufacturers; Another viewpoint is that the introduction of direct sales channels can usually increase the overall profits of manufacturers and supply chains, and retailers can gain additional benefits when the maximum sales volume is high. Research on carbon tax policies has found that low transaction costs are beneficial for manufacturers' profits but not for retailers. Increased sales through direct sales channels will drive manufacturers to increase their investment in carbon reduction technologies; Research on free riding behavior shows that it can enhance online consumer recognition and encourage manufacturers to improve product quality, which is beneficial to the overall supply chain[3]; Another study suggests that when there is a small difference in consumer satisfaction and trust in channel after-sales service, manufacturers should reduce the impact of cross channel factors on direct sales pricing and coordinate the supply chain through profit sharing contracts; In the study of the impact of consumer transfer under capital constraints, it was found that trade credit contracts [4] can alleviate retailers' financing pressure and incentivize ordering behavior. The other dual channel structures show a diversified trend. Relevant studies compared three structures: traditional retailers and electronic retailers' distribution style, enterprise direct sales and electronic retailer combination, and traditional retailers and e-commerce platform consignment. They analyzed the optimal profit and sales strategy choices of manufacturers; There are also studies that divide online models into direct sales, distribution, and consignment sales, and compare the optimal profits and model choices of manufacturers under different structures; In a distributed structure, research has compared the direct ordering and dropshipping models of electronic retailers and found that only when the market size is small and the profit sharing ratio is high, both parties may cooperate through dropshipping; Research on dual channel supply chains for fresh products has found that the trade in strategy generally benefits suppliers, while the optimal strategy for electronic retailers is related to trade in costs. The current research covers sales strategy selection and channel conflict coordination under diversified structures, promoting the development of dual channel supply chain operation theory and providing theoretical support and practical guidance for channel design, pricing strategies, and coordination mechanisms in actual operations

2.2 Research progress on information sharing of supply chain demand forecasting

Vertical information sharing within the supply chain[6] has become a hot research topic in academia in recent years as an important way to control uncertainty risks. Due to retailers being closer to the consumer market, they often have more accurate market information, resulting in asymmetric information within the supply chain. Scholars have conducted research on vertical information sharing between upstream and downstream enterprises in the supply chain, such as comparing inventory strategies and revenue differences between dispersed information structures and joint forecasting in the supply chain composed of suppliers and retailers; In a supply chain with

multiple competing retailers, it is found that demand forecasting information affects decision-making through direct and indirect effects. Retailers are often unwilling to share vertical demand information with manufacturers and tend to share cost information, making information sharing difficult to achieve. There are also studies that classify information states into three scenarios: no information sharing, complete information sharing, and only retailer predicted demand, analyze optimal decisions, and compare the impact of information sharing strategies. In the scenario where manufacturers open direct sales channels, although vertical information sharing can increase manufacturers' profits, retailers lack the willingness to share and need to promote information symmetry through subsidy mechanisms. In addition, the sharing of demand forecasting information will also affect the decision of suppliers to open direct sales channels. Retailers will only actively share information to induce suppliers to open direct sales channels when basic demand and retailer sales costs are low. With the intensification of supply chain competition, some scholars are concerned about the issue of information sharing in the context of competitive supply chains. For example, in a competitive supply chain, the two-way information sharing strategy between manufacturers and retailers is influenced by the intensity of competition between supply chains; When two supply chains sell complementary products, vertical information sharing strategies exhibit different characteristics. There are also studies exploring the impact of manufacturers' investment in after-sales service on information sharing strategies, as well as the issue of complete and partial sharing of retailers' private information when providing after-sales service. Under the competitive supply chain structure, the sharing of demand information among enterprises also involves horizontal information sharing, and it is necessary to analyze the value of information sharing under different information structures (such as no retailer sharing, single retailer sharing, and all retailers sharing). Supply chain contracts can also affect information sharing, such as retailers hiding demand forecasting information under wholesale price contracts, while revenue sharing contracts can incentivize retailers to actively engage in vertical information sharing. In a green supply chain, manufacturers can incentivize retailers to share information by improving green service efficiency and product greenness. In addition, when a supply chain has more accurate predictive information, if its retailers share the information with manufacturers, the information may also be obtained by competing supply chain members.

3 Research method

3.1 Research progress on information sharing of supply chain demand forecasting driven by big data

Big data technology has become the core driving force of supply chain management by improving demand forecasting accuracy and optimizing full chain operations. In the field of demand forecasting, research has shown that it can improve supply chain operational efficiency, reduce demand fluctuation losses, alleviate the bullwhip effect[7], and promote vertical information sharing; Partial achievements have verified the positive impact of big data prediction on organizational performance, revealing the mechanism of the impact of data quality on prediction effectiveness from the three dimensions of data input, processing, and output. Focusing on the big data technology investment decisions and information transparency issues of supply chain members, the big data model has been demonstrated to improve the accuracy of electricity demand forecasting through case studies of power companies. Based on e-commerce platform data, a feature model has been constructed to provide market demand forecasting support for warehouse planning. In other links of the supply chain, big data technology has penetrated into the entire process of procurement, production, warehousing, transportation, and sales. Research has found that it runs through multiple links and provides guidance for enterprise applications. Empirical evidence shows that it has a

significant positive impact on supply chain financial integration and customer relationship improvement. Through game models, the impact of big data information investment on supply chain cost reduction and coordination is explored. Pricing and investment strategies for supply chain members using big data targeted advertising are studied. A big data based integrated management model for port logistics supply chain is proposed to enhance the comprehensive management capability of the Internet of Things environment. It is pointed out that centralized utilization of procurement data can reduce enterprise operating costs. For fresh food supply chain, big data based procurement, production, and distribution optimization strategies are proposed. As a key path to reduce uncertainty risks, demand forecasting information sharing focuses on the problem of information asymmetry in the upstream and downstream of the supply chain in terms of vertical information sharing. By comparing inventory strategies and benefits under decentralized information structures and joint forecasting, it is found that retailers are unwilling to share demand information due to indirect effects and are more inclined to disclose cost information. Research shows that manufacturers will transfer information to retailers with poor information quality. The impact of information sharing strategies is analyzed by distinguishing between three scenarios: no sharing, complete sharing, and retailer forecasting. It is pointed out that in the direct sales channel of manufacturers, information sharing needs to be promoted through subsidy mechanisms. It is found that retailers will only actively share information to induce suppliers to open direct sales channels when basic demand and retailer costs are low, and the risk of supplier information leakage is explored. In the context of competitive supply chains, this study investigates the impact of competition intensity between supply chains on bidirectional information sharing, analyzes the vertical information sharing of complementary product supply chains, explores the impact of after-sales service investment on information sharing, studies the problem of complete/partial sharing of private information among retailers, compares three information structures: no sharing, single retailer sharing, and full retailer sharing. It is found that under wholesale price contracts, retailers hide information while profit sharing contracts promote active sharing. It is pointed out that manufacturers can incentivize retailer sharing by improving green service efficiency and product greenness, revealing that high-precision predictive information sharing may be obtained by competitive supply chains. Although existing research covers vertical and competitive scenarios, the issue of heterogeneous demand information sharing and leakage among multiple sales nodes in a dual channel supply chain still needs to be further explored. This article will combine the investment characteristics of big data technology and analyze the equilibrium strategy of two-way information sharing and information leakage from the perspective of direct sales and distribution dual channel structures.

3.2 Construction of Information Sharing Strategy Model for Demand Forecasting of Direct Sales

This chapter constructs a direct sales dual channel supply chain model, consisting of manufacturers who master direct sales channels and traditional retailers forming a secondary supply chain. The two obtain heterogeneous demand forecasting information fR and fM through investment in big data technology to cope with random market demand fluctuations. The demand function is set to

$$P_i = a - q_i - \gamma q_i + \varepsilon (\text{i,j=M,R and i} \neq \text{j})$$

Among them, a is the maximum willingness of consumers to pay, $q_i$is the shipment volume of channel i, γ is the intensity of competition between channels ($0< \gamma <1$), and ε is the random fluctuation term (obeying N ($0, \sigma \sigma^2$)). The investment in big data technology includes two stages

of data collection and processing: channel i first collects data packets with a data volume n_i, $d_{ik} = \mathcal{E} + e_{ik}$ (e_{ik} is observation noise, obeying $N(0, \sigma_{ie}^2)$), and then obtains demand forecasting information $f_i = \varepsilon + \sum_{k=1}^{n_i} e_{ik}/n_i$ through mean processing (f_i is an unbiased estimate of ε, and f_R and f_M are independently and identically distributed). The accuracy of prediction information$t_i = \mathrm{Var}(\varepsilon)/E[\mathrm{Var}(f_i|\varepsilon)]$ increases with the increase of data volume $n_i$or the decrease of observation noise varianceσ_{ie}^2, and the investment cost of big data technology increases

$C(t_i)$satisfies tha$C(t_i) \geq 0$an$\vartheta C(t_i)/\vartheta t_i > 0$. Based on this, the supply chain information status can be divided into four types: no information sharing (neither party discloses predictive information), forward information sharing (manufacturer discloses while retailer hides), reverse information sharing (retailer discloses while manufacturer hides), and bidirectional information sharing (both parties disclose). The decision-making sequence follows a time series: supply chain members first formulate information sharing strategies, and then determine channel shipment volumes based on private forecast information. Figure 1 shows the direct sales dual channel supply chain structure,

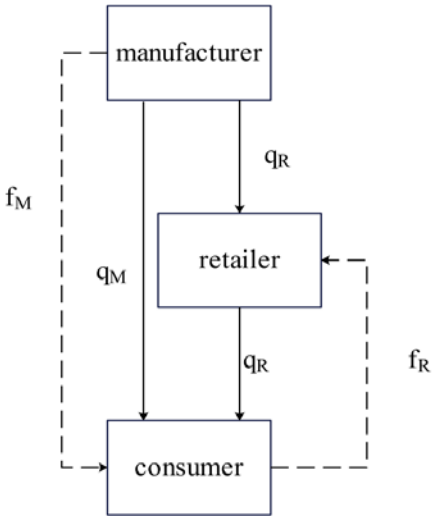

Figure 1 The direct sales dual channel supply chain structure

Describe the time series and decision sequence with Figure 2.

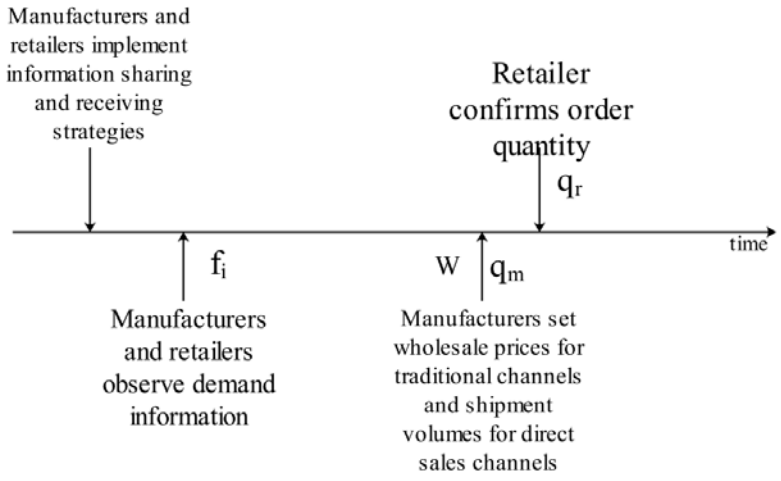

Figure 2 depicts the time series and decision sequence

This chapter analyzes the impact mechanism of big data technology investment and demand forecasting information on the pre profit of supply chain members by comparing the optimal decisions under four information sharing scenarios, and ultimately proposes an equilibrium information sharing strategy.

3.3 Bayesian game analysis under different information sharing scenarios

In the absence of information sharing, manufacturers and retailers make decisions based on private demand forecasting information, and the demand function includes maximum willingness to pay, channel shipment volume, competition intensity, and random fluctuation terms. The demand forecasting information generates agility effects (improving the agility of channel product quantity decisions in response to market fluctuations) and strategic effects (manufacturers adjusting wholesale prices to cope with downstream order quantity changes, increasing double marginal effects). Pre profit consists of a certain portion, uncertain returns, and investment costs in big data technology. Uncertain returns are positively correlated with market volatility, and manufacturers can increase uncertain returns through technological upgrades. Retailers expect returns to be positively affected only by their own technological investments, but there is a threshold effect on manufacturers' returns due to the impact of retailers' technological levels. When sharing positive information, manufacturers share demand forecasting information, and the strategic effect is always higher than the agility effect. Retailers' order quantity decisions are influenced by manufacturers' shared information, and the direction of the effect is related to the retailer's technological level. Manufacturers' expected profits are only affected by their own technological investment. There is a threshold for the impact of technological upgrades on retailer profits, with positive spillover below the threshold and negative spillover above the threshold. Under reverse information sharing, retailers share information, and manufacturers' wholesale price decisions are only affected by reverse shared information. The agility effect of direct sales channel shipment volume decisions is related to the manufacturer's technical level. When the threshold is below, reverse information improves agility, and when it is above, it weakens. Retailers' order quantity is only affected by their own information, and there is a threshold effect of manufacturer technology upgrades on the agility of direct sales channels. When complete information sharing occurs, demand forecasting information is positively correlated with manufacturer decision variables. In an information symmetric environment, technological investment improvement will have a positive impact on the accuracy of information for supply chain members, increasing the agility and strategic effects of decision-making. In addition, sharing information by manufacturers can improve the agility of traditional channel order quantities. The marginal uncertainty income brought by investing in big data technology by supply chain members is equal to the increase in marginal uncertainty income caused by sharing information. In four scenarios, technology investment changes the decision effect by affecting the accuracy of predicted information, thereby affecting profit distribution. It is necessary to study the two-way information sharing equilibrium strategy by comparing the expected returns of each information state in advance.

4 Results and discussion

4.1 Optimal Decision and Benefit Analysis under Supply Chain Information Sharing Strategy

In different contexts of supply chain information sharing, the impact mechanism of demand forecasting information on member decision-making and revenue shows significant differences. When there is no vertical information sharing, manufacturers need to determine wholesale prices and quality improvement investments through reverse induction due to a lack of demand

information. Retailers engage in Cournot games based on their own demand forecasts[8], and their private information has a positive agility effect on order quantity. E-retailers respond faster due to more accurate information; Retailers' own big data investments increase uncertain returns, while competitors' investments decrease their own returns. The intensity of channel competition is negatively correlated with returns. When a single channel is vertically shared and there is no information leakage, manufacturers only receive shared channel information, and their wholesale prices and quality improvement investments are affected by this information. Retailers' order quantities rely on their own information; Information sharing enhances manufacturers' responsiveness through strategic and agility effects, thereby affecting profit distribution. When there is dual channel sharing and information leakage, the supply chain achieves information symmetry, and demand forecasting information has a positive impact on the decision-making of all members. Manufacturers have the same strategic adjustment range for both channels, and retailers' order quantity agility tends to converge; The upgrade of big data technology in any channel increases the revenue of competitive channels through the "free riding effect", and consumer quality sensitivity and channel competition intensity have positive and negative effects on revenue, respectively. Ultimately, supply chain members need to dynamically adjust their information sharing strategies in response to market demand fluctuations, cost structures, and competitive environments to achieve maximum decision-making efficiency and revenue.

4.2 Model experiment

In the retail supply chain, the market data-driven demand forecasting information sharing and inventory coordination mechanism presents complex strategic interactions due to differences in information sharing status. The manufacturer's information leakage strategy depends on the sharing context: when sharing through a single channel, if the big data technology level of the unshared channel is low, the manufacturer tends to leak information to enhance the competitiveness of that channel; If the technology level of the unshared channel is high, avoid leakage to prevent the weakening of competitive advantage. When sharing through dual channels, manufacturers tend to leak information to achieve supply chain information symmetry, reduce bullwhip effects, and improve overall agility. Retailers' shared decision-making is significantly influenced by consumer quality sensitivity. When consumers are moderately sensitive to product quality, retailers are willing to share demand information; If the sensitivity is too low or too high, the willingness to share decreases - when the sensitivity is too low, information sharing may exacerbate the double marginal effect; When the sensitivity is too high, the spillover effect caused by information leakage may weaken one's competitiveness. Specifically, when a single retailer shares, whether the manufacturer leaks or not directly affects the retailer's strategy: in the context of leakage, the retailer is only willing to bear the risk of leakage and share information when the consumer's quality sensitivity is within a reasonable range; When not disclosing, retailers need to balance shared value and competitive risk. The state of information sharing ultimately affects the balance of the supply chain: when consumer quality sensitivity is extreme, the supply chain may maintain a state of no sharing (NNN); When the sensitivity is moderate, it may form a single channel sharing (NSN) [9] or dual channel sharing and leakage (LSS) state. Under dual channel sharing, information symmetry improves the decision-making agility of all members, and any channel technology upgrade benefits competitive channels through the "free rider effect". Consumer quality sensitivity and channel competition intensity have positive and negative effects on revenue, respectively. Ultimately, supply chain members need to dynamically adjust their information sharing and inventory coordination strategies in response to market demand fluctuations, cost structures, and competitive environments to achieve decision efficiency and maximize profits.

4.3 Effect analysis

In the retail supply chain, the market data-driven demand forecasting information sharing and inventory coordination mechanism is significantly affected by information leakage scenarios and consumer quality sensitivity. When manufacturers face single channel sharing, if the big data technology level of the unshared channel is low, they tend to leak information to enhance the competitiveness of that channel; If the technology level of the unshared channel is high, avoid leakage to prevent the weakening of competitive advantage. When sharing through dual channels, manufacturers tend to leak information to achieve supply chain information symmetry, reduce bullwhip effects, and improve overall agility. The sensitivity of consumers to product quality (θ) is a key influencing factor for retailers' shared decision-making: when θ is moderate, retailers are willing to share demand information; If θ is too low or too high, the willingness to share decreases - when θ is too low, information sharing may exacerbate the double marginal effect; When θ is too high, the spillover effect caused by information leakage may weaken one's competitiveness. The part of the manufacturer's expected profit that is affected by market demand uncertainty is positively correlated with θ, and increases with the increase of information transparency. The manufacturer's profit is highest when there are dual channel sharing and leakage. The expected profits of traditional retailers and electronic retailers also increase with the increase of θ, but information leakage behavior will weaken their willingness to share. For example, the θ threshold for traditional retailers to share information has increased from 1.3594 to 1.3800 due to information leakage, while for electronic retailers it has increased from 1.4943 to 1.5000, indicating that information leakage has increased the cost for manufacturers to guide information sharing. Ultimately, supply chain members need to dynamically adjust their strategies based on θ, cost structure, and competitive environment to achieve maximum decision-making efficiency and revenue.

5 Conclusion

In the retail supply chain, the market data-driven demand forecasting information sharing and inventory coordination mechanism is significantly influenced by channel structure and information leakage scenarios. In a direct sales dual channel supply chain, traditional retailers are unable to obtain value-added benefits through reverse information sharing, and information balancing strategies[10]only exist in situations of forward sharing and no sharing; When channel competition eases, manufacturers tend to share information, while retailers only accept sharing when their own investment level in big data technology is low, forming a positive sharing equilibrium; If competition is fierce, manufacturers hide information and maintain a state of no sharing. In a distributed dual channel supply chain, information status is divided into five categories, and manufacturer decisions are driven by product quality improvement technology and information leakage motivation: when the technology level is high, manufacturers focus on improving investment agility to cope with market risks; On the contrary, strategic wholesale prices are used to compress retailers' profit margins. The behavior of information leakage depends on the accuracy of information sharing channels - if the technological level of competing channels is low, manufacturers tend to leak information to enhance their competitiveness; If the competitive channel technology is mature, avoid leakage. The realization of information symmetry in downstream sales channels requires that manufacturers ensure information security, and both channels believe that quality improvement can effectively stimulate consumption and avoid excessive loss of competitive advantage; If information is leaked, retailers will only follow up on sharing strategies when consumers highly value product quality. The research shortcomings include the lack of exploration

of contract incentive mechanisms, endogenous decision-making in big data technology investment, and some information sharing scenarios. In the future, Pareto improvement and partial sharing strategies can be studied based on transfer payments, revenue sharing contracts, and endogenous investment variables.

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