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The Mutual Feedback Mechanism and Collaborative Management of Green Cost Allocation and Bullwhip Effect

Hanruiyan Jin [1, *], Junyan Li [2] and Mingjie Wang [3]

[1] Shenzhen Hongkong Pui Kiu College Longhua Xinyi School, Shenzhen, China

[2] School of Urban Construction, Yangtze University, Jingzhou, China

[3] Colege of Civil Engineering, Nanjing Tech University, Nanjing, China

* Corresponding Author Email: alice080608@gmail.com

Abstract. Against the backdrop of the "dual carbon" goals in China and the rising threshold for green trade, how to reasonably allocate the incremental costs generated by the greening of the supply chain among the upstream and downstream has become a key factor affecting operational stability and collaborative performance. This study takes green cost allocation and the bullwhip effect as its theme, sorts out the causes of the bullwhip effect and its amplification mechanism in the green transformation, and reveals how the allocation uncertainty forms a negative cycle of "rising green costs - intensified demand fluctuations" through information delay and order batch adjustment. It also proposes a positive path with carbon data transparency, dynamic contracts and inventory/scheduling coordination as the key points, and builds a closed loop of "fair allocation - accurate information - fluctuation suppression - performance improvement". The research conclusion indicates that in manufacturing, fast-moving consumer goods and cross-border supply chains, a green information sharing platform should be established based on the specific conditions of each chain, order fluctuation thresholds should be set, and a green processing window should be included to achieve dual goals of the environment and operation.

Keywords: Green Cost Allocation, The Bullwhip Effect, Information Sharing, Dynamic Contract, Game Model.

1. Introduction

Contrasting the growing global climate of green trade obstacles and the so-called dual carbon objective, the green transformation of supply chains has turned into an inescapable requirement of the enterprises that face pressures in policy and markets simultaneously.

Environmental performance and corporate reputation can be improved long-term through green investments, which could include the implementation of low-carbon technologies, non-toxic materials, and re-engineering clean production processes. But the distribution of the ancillary costs incurred by these investments between the stakeholders in the supply-chain has not yet been addressed as a practical challenge, and there is no systematic solution to the so-called problem.

As an example, electronic manufacturers can invest heavily in modernizing their production lines to meet the high standards imposed by the Carbon Border Adjustment Mechanism (CBAM) of the European Union (EU). Without a clearly understood cost sharing framework, downstream distributors tend to have the order adjusted due to cost uncertainty, which reduces the responsiveness of the supply chain.

This process enhances the classic bullwhip effect, whereby the effect of information about demand is amplified as it flows up the supply chain, with the distribution of green costs being further obscured, which results in a vicious circle: "The green cost upgrade increases the bullwhip effect" [1]. This cycling nature critically impacts the general stability and sustainability of the supply chain.

The scarcity of a green cost-sharing system is the first pinpoint that obstructs multi-purpose work in green change. Enterprises are increasingly pressured to internalise these costs as they strive to balance

operational efficiency and compliance with regulations, especially as environmental protection laws are revised frequently, and green thresholds are being raised.

Take the fast-changing consumer goods industry case: a top brand offered complete biodegradable packaging but was unable to reach a cost sharing deal with channel partners. As a result, risk mitigation by partners involved sudden order cuts, causing chaos in upstream production planning and overstocking [2].

Other businesses strive to engage in local cost cooperation through information sharing and green contracts, including the framework of the closed-loop supply chain in the automotive industry, aimed to enhance the efficiency of resource recycling [3]. However, the existing local collaborative approaches are still limited in their practical implementation; there are concerns regarding data security, privacy, and the realization of green contracts without effective oversight that restricts the scope of effectiveness.

The majority of extant literature has focused on the analysis of the uptake of green technologies, or on the bullwhip effect, and relatively little work has factored in policy dynamics, corporate behavior, and multi-level supply-chain arrangements, as part of an integrated theoretical framework. The consequence of this disconnect is that theoretical research falls behind the necessities of empirical research; e.g. numerous papers have failed to discuss how often a firm changes environmental policy, a failure that can hinder supply-chain coordination [4].

Moreover, some researchers concede that information sharing may reduce the bullwhip effect, but further studies are needed to uncover how the open sharing of environmental information (e.g., carbon footprints, recycling rates) can affect the ordering behaviour of both upstream and downstream participants in the green transition.

Therefore, current literature adequately discusses the feedback between green costs allocation and the bullwhip effect in both directions, without empirical testing in the framework of dynamic policy and corporate behaviour. This paper aims to provide a systematic explanation of these interaction processes and construct an interactive model of management, therefore, offering a theoretical basis and roadmap to the realization of a state of green operation within the framework of supply-chain cooperation.

2. Formation Mechanism and Control of the Bullwhip Effect

The Bullwhip Effect refers to the phenomenon where the volatility of demand information amplifies at each stage as it moves upstream in the supply chain. Lee et al. first systematically expounded this concept in 1997, and it has since become a core research topic in supply chain management. Its formation mechanism mainly stems from four key factors: demand forecast updates, order batches, price fluctuations and rationing games. In practice, enterprises at each supply chain node conduct demand forecasting based on local information. Then, they transmit this demand information to their upstream partners through orders. The information distortion generated during this process will be amplified along the transmission path. Therefore, upstream suppliers are confronted with seriously distorted demand signals. This will eventually lead to low operational efficiency, such as soaring inventory costs, declining service levels and capacity abuse.

In recent years, with the deepening of the concept of sustainable development, the research on the bullwhip effect has shown a new trend of integrating environmental management. Scholars like Crump pioneered the concept of the "green bullwhip effect". They indicate that the demand changes driven by sustainable lifestyles may trigger a new type of demand amplification. This presents new challenges to the traditional bullwhip effect theory [5]. Through large-scale empirical studies, Song and Zhang revealed the intrinsic connection between the bullwhip effect and the cost structure of enterprises. They found that enterprises affected by the bullwhip effect tend to adopt a more flexible cost structure compared to ordinary enterprises, that is, a lower fixed cost and a higher variable cost, to cope with the uncertainty of demand. This discovery provides a foundation for understanding the

choices made by enterprises when facing demand fluctuations [6]. Zheng and Zou's latest research, from a regulatory perspective, found that industry information disclosure regulation can alleviate the bullwhip effect by reducing environmental uncertainty and improving information quality. Their research provides a new idea and method for managing the bullwhip effect [7]. In terms of control strategies, the traditional methods mainly include information sharing, Vendor Managed Inventory (VMI), and Collaborative Planning, Forecasting and Replenishment (CPFR). Furthermore, to achieve a green transformation, these methods also need to be combined with environmental protection requirements. For instance, enterprises can utilize blockchain technology to establish a carbon data sharing platform. This not only enhances information transparency but also ensures the authenticity and integrity of environmental data. Additionally, they can design supply chain contracts that include green performance clauses, integrating environmental and operational goals into the contract framework. These are currently relatively advanced methods for controlling the bullwhip effect in supply chain management.

3. Green Cost-Sharing Mechanisms

Green cost allocation is a reference to the process and mechanism through which the supply chain participants negotiate, apportion and compensate the incremental costs caused by the green transformation. Its theoretical foundation is grounded on the positive externality nature of the green investment. In other words, the investment companies cannot simply enjoy the fruits of the increased value due to environmental enhancement. Hence, mecha-nism innovation is required to allow the supply chain partners to make a cost and bene-fits and maximize the total green performance.

In empirical studies by Liu Hongxia and Sun Yanan, a deep investigation into the inner workings of the mechanism by which green investment leads to cost-sharing in the supply chain was carried out [2]. The study has established that the green investment facilitates the cost-sharing of the supply chain by use of signal and trust. This effect is more significant in the case when supply chain businesses are highly geographically agglomerated and are given high media coverage. It is also interesting to point out that the studies indicate that relative to downstream customers, the green investment is more effective in facilitating cost-sharing with the upstream suppliers which connotes differences in the behavior of the business at various point of supply chain. Through the empirical research findings on the cost-sharing driving mechanism, Hou Jian et al. advanced the investigation of the influence of the cost-sharing financing model theoretically by developing a game theory model. They have realized that this model can make the products greener and the profit level of the entire supply chain becomes more profitable. In their study, they have discovered that when retailers choose to green their products, manufacturers with the high green financing cost may attain a Pareto improvement, which offers insightful theoretical prescriptions to the development of cost-sharing arrangements [8].

Policy climate is a major issue affecting the design and effectiveness of the green cost-sharing mechanism. When addressing the two research and development subsidy policies and consumption subsidy policies, Yan et al obtained the outcome that various methods of subsidy give rise to varying optimum sharing ratios and social welfare. As the supply chain embraces the most suitable cost of Research and Development (R&D) cost allocation ratio, R&D cost subsidies have the best efficiency in improving the profitability whereas consumer subsidies are better placed to augment the overall amount of social welfare [9,10]. The study of Lin Wen et al. found the so-called green bullwhip effect, i.e., the pressure of gov-ernment green procurement is increased, when it propagates in the supply chain of the upstream direction. It shows that the decision-making process on the cost sharing is propagated significantly under policy pressure that is passed through the supply chain network. These results could indicate that the nature of green cost-sharing procedures should consider the nature and complexity of the policy environment [11].

4. The Mutual Feedback Mechanism Between Green Cost Sharing and the Bullwhip Effect

There is a close two-way feedback relationship between green cost allocation and the bullwhip effect. This relationship operates through both negative and positive aspects, forming a feedback loop mechanism. Understanding this feedback mechanism is crucial for people to address the predicament of increased green costs leading to intensified operational fluctuations.

4.1. Negative Feedback Path

The negative feedback loop is characterized by an escalating operational fluctuation caused by the uncertainty in cost allocation. This is mainly achieved through two mechanisms: information transmission and behavioral patterns. In terms of information transmission, the ambiguity in green cost allocation leads to delays or distortions in the transmission of environmental data (such as carbon footprints and recycling information) among various levels of the supply chain, thereby resulting in green information delay (GID). According to the research of Zhu and Sarkis, the lack of information sharing in green supply chain management can significantly amplify operational volatility, and this impact is more pronounced in a dynamic policy environment [12]. In terms of order behavior, enterprises respond to the uncertain green cost pressure by making irrational order volume adjustments (OBA), such as suddenly increasing or decreasing the order quantity to shift the cost pressure. The delay or distortion of information transmission intensifies enterprises' perception of cost uncertainty, prompting them to adopt more conservative or aggressive ordering behaviors. This unstable order, in turn, further distorts the transmission of information, forming a mutually reinforcing vicious cycle.

This negative cycle has been further intensified under the pressure of policies. Lin Wen et al. 's research found that the "green bullwhip" effect was more pronounced during the central environmental inspection activities, indicating that the sudden surge in policy pressure intensified the operational fluctuations in the supply chain [11]. When companies are confronted with sudden environmental penalties or customer environmental complaints, they usually tend to shift costs to the upstream through the order game. This short-term behavior gradually amplifies throughout the multi-layered supply chain, eventually leading to a decline in overall operational efficiency. The empirical research by Song and Zhang shows that this volatility eventually leads enterprises to choose a stricter cost structure, further reducing their ability to cope with the uncertainty of green costs and forming a self-reinforcing vicious cycle [6].

4.2. Positive Feedback Path

The positive feedback path is manifested as a virtuous cycle of "collaborative mechanism → dual performance improvement", providing a feasible way to break the negative cycle. Firstly, establishing a transparent information-sharing platform for green costs (such as a blockchain-based carbon data system) can simultaneously enhance the fairness of cost allocation and the accuracy of demand information. Zheng and Zou's research indicates that industry information disclosure regulation alleviates the bullwhip effect by enhancing information quality, providing theoretical support for the construction of such platforms [7]. Secondly, designing green dynamic contracts that clearly define the cost-sharing ratio and order stability requirements can reduce gambling costs and enhance collaboration efficiency. The game theory model proposed by Hou Jian et al. indicates that a reasonable cost-sharing model can enhance the greenness of products and the overall profit level of the supply chain, providing specific guidance for contract design [8].

The policy environment plays a crucial catalytic role in the positive path. Ma Jingmei et al. found that the carbon emissions trading policy enhances supply chain resilience by boosting "green relationship capital", but this effect shows significant heterogeneity: the policy effect is more pronounced in regions that adopt a mixed carbon quota allocation method, while the resilience enhancement effect is stronger for enterprises with greater market influence [9]. Liu Tingli and Yun Shiji's research indicates that the service-oriented transformation of manufacturing enhances supply chain resilience

by alleviating the bullwhip effect. This effect is more significant in high-tech enterprises and those with a high level of artificial intelligence application [13]. These findings indicate that achieving a positive feedback path requires a coordinated combination of policy design, enterprise capabilities and technical conditions.

4.3. Differential Manifestations and Managerial Implications

Feedback mechanisms exhibit systematic differences in various supply chain structures. In the manufacturing supply chain, environmental technology investments led by core enterprises (such as upgrading low-carbon equipment) need to support a reasonable cost-sharing mechanism. Otherwise, they might trigger resistance from small and medium-sized suppliers through order batch adjustments [1]. In the retail and fast-moving consumer goods supply chains, the cost-sharing game over green packaging and certification costs is more likely to distort the demand signals between brands and distributors [5]. In the global supply chain, the differences in environmental regulations among countries have increased the complexity of coordination, and it is necessary to establish cross-border cost-sharing and information-sharing mechanisms.

From the perspective of management practice, a systematic collaborative strategy is needed to address the feedback dilemma. At the strategic level, enterprises should establish green governance mechanisms and partner selection criteria, and incorporate environmental performance and collaboration capabilities into the supplier evaluation system. At the tactical level, green dynamic contracts and information-sharing platforms should be designed, with clear cost-sharing principles and information-sharing standards. At the operational level, green constraints need to be integrated into production scheduling and logistics planning. This can be achieved by establishing a green processing window and adopting priority scheduling rules, in order to balance environmental requirements with operational efficiency. Through the three frameworks of information transparency, contract coordination, and operational flexibility, enterprises can systematically manage the feedback relationship between green cost sharing and the bullwhip effect, ultimately achieving a dual improvement in environmental and operational performance.

5. Conclusion

The current paper will examine in a systematic way the interactive relationship between the bullwhip effect and the supply chains as to green cost-sharing mechanisms. According to research, there is a two-way interaction: incomprehensible distribution of costs reinforces the bullwhip effect by disfiguring information and making irrational decisions on orders in a vicious circle of green cost-operational fluctuation. On the other hand, the fluctuations can be subdued with the help of transparent cost-sharing, coordination of information, and constraints of the contract, which will result in two advantages: protection of the environment and the efficiency of operations. The performance of such a mechanism differs depending on the types of the different supply chains, requiring the specific approach depending on a particular industry and policy.

A synergistic process must be identified to deal with the interaction of the green cost-sharing strategy and the bullwhip effect by means of coordinating inventory, designing contracts, and scheduling production. First, adopt a green cost inventory model (transparent) that calculates order quantity, reorder point with carbon taxes and certification charge on them and distributes these expenses across the supply chain echelons in proportionate measure. An example is that so as to reduce order volatility, joint decisions on safety stocks based on carbon data platforms may help. Second, develop dynamical green contracts, which clearly stipulate the ratios between costs and order adjustment limits, including a cap of a 10 per cent order change to improve system stability. Lastly, incorporate green processes in production scheduling through creating green processing win-dows, introduction of priority scheduling rules to tradeoff environmental require-ments with delivery risks. The current studies should also focus on how policies affect future, the introduction of digital technology to share

information and control bullwhip effects, and empirical studies across industries to develop both theoretical background and practice of green supply chain management.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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