Information Sharing via Digital Freight Brokerage Platforms: Improving Operational Responsiveness to Carrier Freight Rejection

Ye Shi†, Amir A. Alwan*, Xiaohang Yue‡
†School of Management, University of Science and Technology of China
*Booth School of Business, The University of Chicago
‡Sheldon B. Lubar School of Business, University of Wisconsin–Milwaukee

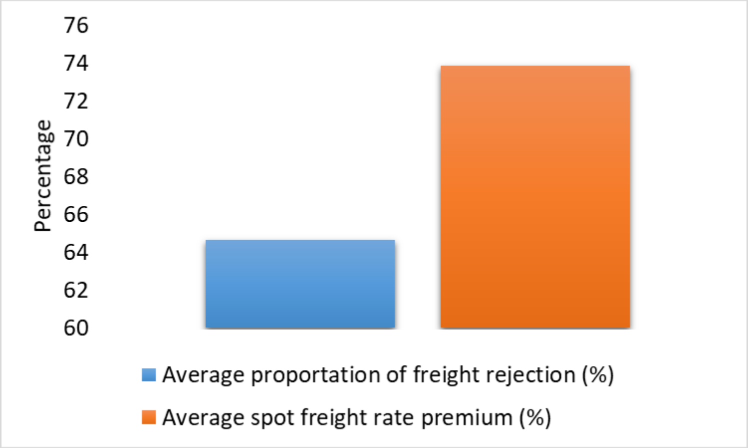
Nowadays, supply chain operations frequently encounter disruptions due to carrier freight rejection. Motivated by real-world practice, this paper studies the operational value of digital freight platforms' information sharing with firms in supply chains, an effort aimed at enhancing operations in response to freight carrier rejection. We develop a theoretical model in which a digital freight platform shares its superior predictive information on uncertain freight market conditions with a single supply chain, consisting of a retailer (i.e., the shipper working directly with the platform) and a manufacturer, allowing them to better anticipate carrier freight rejection. Our findings demonstrate the economic incentives behind a digital freight platform's information sharing by quantifying the benefits to the relevant players, and show that the platform prefers to share information fully with both the retailer and manufacturer in the supply chain over sharing exclusively with the retailer as the manufacturer's production diseconomy increases. We also consider a digital freight platform's information sharing to competing supply chains, and find that the platform's equilibrium information sharing formats transition gradually as the manufacturer's production diseconomy increases. Our results yield several insights into the management of digital freight platforms' information sharing. First, the probability of freight carrier rejection is a positive factor that drives the platform to improve the accuracy of its predictive information. Second, the platform experiences disruptive improvements in its information accuracy as competition increases. Finally, digital freight platforms' information sharing could have a negative spillover effect on other solutions aimed at alleviating carrier freight rejection.

Key words: digital freight platform, carrier freight rejection, information sharing

1. Introduction

Modern supply chain logistics are increasingly affected by uncertain freight market conditions. A common phenomenon that exacerbates the impact of such uncertainty is *carrier freight (load) rejection*, particularly prevalent in the context of truckload shipping (Caplice 2021, Acocella et al. 2022, Scott et al. 2017). Typically, shippers (e.g., downstream retailers) in supply chains aim to secure the freight rates for transporting their goods (or materials) in advance by signing long-term freight contracts with carriers. When shippers need to transport their goods, they first tender the load requests to their contracted carriers, who are expected to accept and haul the goods at the the contracted freight rates. However, due to the non-binding nature of freight contracts, the contracted carriers can opt to reject the requests. Evidence suggests that carrier freight rejection depends on freight market conditions. Specifically, during tight market conditions—when freight demand surpasses supply and spot freight rates exceed contract rates—carriers are more likely to reject and offer their capacity on the spot market with higher expected profit (Caplice 2007, Scott et al. 2017). In instances where carrier freight rejection occurs, shippers are forced to swiftly secure alternative options, such as for-hire or private carriers from the spot freight market. This often results in a significant spot premium, which can reach up to 60% in the U.S. freight market (Scott et al. 2017, Acocella et al. 2022). Figure 1 also shows a recent, albeit extreme, example of carrier freight rejection in a local Chinese freight market, which was partially triggered by a resurgence of the COVID pandemic in March 2022. In this example, over 60% of shippers were rejected by their contracted carriers, and were forced to pay an average spot premium of 70%.

Figure 1 **An example of carrier freight rejection in a tight freight market in China. The data is provided by a leading digital freight platform in China, which describes the average proportion of freight rejection (over 60%) and spot freight rate premium (over 70%) in March 2022.**



Fortunately, the rise of digital freight brokerage platforms, such as Convoy (www.convoy.com) and Uber Freight (www.uberfreight.com), offers firms within supply chains good opportunities to improve their operations subject to carrier freight rejection. On the one hand, these platforms leverage advanced information technologies and matching algorithms to help firms facing carrier freight rejection, enabling them to locate alternative for-hire or private carriers from the spot freight market in real time (Miller et al. 2020, Zhou and Wan 2022). On the other hand, unlike individual firms that often have access to limited information (e.g., public freight index) on freight market conditions, digital freight platforms are also big data analytics centers and possess superior knowledge about these conditions. Moreover, digital freight platforms, including Convoy and Uber Freight, have established information sharing programs for shippers (e.g., sellers, retailers, distributions) in supply chains by offering integrated data exchange interfaces (Pyzyk 2021). Based on the superior information shared by these digital freight platforms, those shippers are better equipped to anticipate carrier freight rejection and make responsive operational adjustments to alleviate the negative effect of this phenomenon.

Though information sharing programs proposed by digital freight platforms become prevalent in practice, the theoretical understanding on the operational value of these information sharing initiatives is still limited. This paper aims to address the effect of information sharing via digital freight platforms on improving supply chain operations in response to carrier freight rejection. The motivation for this work partially stems from a research collaboration with an leading digital freight platform in China.[1] Recently, this platform initiated an information sharing program that provides predictive information on uncertain freight market conditions to supply chains, presenting two strategic dilemmas during the program's implementation. First, given a supply chain, the platform initially employed a strategy known as "partial information sharing", under which the platform shared information only to shippers (who are mostly downstream firms) that work with the platform in the supply chain. However, realizing that the predictive information could also be beneficial to other players (e.g., upstream firms) within the supply chain, the platform was encouraged by local government agencies to adopt another strategy called "full information sharing", under which the platform shared the information to all the firms (including those do not work with the platform directly) in the supply chain. This leaves the platform with the strategic choice between the partial and full information sharing strategies. Second, the accuracy of the predictive information is another strategic choice when implementing the information sharing program. More accurate predictive information makes the program more attractive to firms in supply chains by enabling them to better respond to carrier freight rejection, and even gaining a competitive advantage, but costs the platform more in the development of advanced data analytics techniques. It is noteworthy that these two strategic problems are common across digital freight platforms worldwide. For instance, digital freight platforms in the U.S. also widely adopt the strategy of partial information sharing (Pyzyk 2021), and might switch to the strategy of full information sharing under the U.S. government policy of encouraging freight data sharing to entire supply chains (Zimmerman 2022).

1.1. Research Questions

From the aforementioned practice, we see that information sharing through digital freight platforms could be an effective solution for improving supply chain operations in response to carrier freight

---

[1] For confidential reasons, the details about the platform are omitted.

rejection, however brings new operational challenges to supply chains and platforms. This work aims to develop some theoretical insights on the management and value of digital freight platforms' information sharing by addressing the following research questions:

(a) How can we quantify the impact of a digital freight platform's information sharing on the operations of downstream and upstream firms within a supply chain in response to carrier freight rejection, as well as the platform's own operations?

(b) How should a digital freight platform choose between different information sharing strategies (i.e., either partial or full information sharing) when implementing an information sharing program?

(c) How does a digital freight platform optimize the accuracy of its predictive information? In the context of supply chain competition, would the platform invest more to improve the accuracy of its predictive information as the competition intensifies?

To answer these questions, we develop an analytical model consisting of a supply chain and a digital freight platform. In the supply chain, a retailer ("she") sells goods to a Cournot-type market of customers and procures these goods from a manufacturer ("he") with production diseconomy. After placing an order with the the manufacturer, the retailer requires transportation services for the procured goods. Despite securing a fixed freight rate via a long-term freight contract, the retailer may still encounter carrier freight rejection, which depends on uncertain freight market conditions. There are two possible freight market conditions: soft or tight. In a soft freight market, carrier freight rejection doesn't occur and the retailer pays the contracted freight rate. In a tight freight market, however, carrier freight rejection occurs with a probability, referred to as the *probability of carrier freight rejection*. If carrier freight rejection indeed happens, the retailer must find an alternative for-hire carrier over the digital freight platform, incurring a spot freight rate to the carrier and a brokerage fee to the platform.

All players have access to public prior information about the uncertain freight market conditions. In addition, the platform has private information about the freight market conditions and can improve the accuracy of this private information via costly efforts. The digital freight platform can select one of two strategies for sharing this private information with the players in the supply chain: sharing only with the retailer (i.e., partial information sharing), or sharing with both the retailer and the manufacturer (i.e., full information sharing). In this model, all the players engage in a multistage game as follows. Initially, the platform makes two-fold strategic information decisions of optimizing the accuracy level of its private information and choosing its information sharing strategy. Given the platform's strategic information decisions, the manufacturer first announces the wholesale price, then the platform determines the brokerage fee, and finally, the retailer decides the order quantity.

We also extend the base model by considering a digital freight platform's information sharing to two supply chains engaging in Cournot competition. This allows us to examine the impact of supply chain competition on the platform's strategic information decisions.

1.2. Key Findings

By exploring the base model, we first analyze the effect of a digital freight platform's information sharing on both firms in the supply chain and the platform itself. Specifically, relative to the benchmark of no information sharing, we find that any degree of information sharing by the platform, whether it be partial or full information sharing, benefits all relevant players by improving their responsiveness to carrier freight rejection. This result provides an explanation for the widespread use of information sharing programs proposed by digital freight platforms in practice, by demonstrating the economic incentives. We then compare the platform's two information sharing strategies and find that relative to partial information sharing, full information sharing benefits the manufacturer by enhancing his responsiveness to carrier freight rejection, but hurts the retailer and the platform because of the double marginalization effect. As a result, under side payments from the manufacturer to both the retailer and the platform, the platform's equilibrium information sharing strategy is full information sharing only if the manufacturer's production diseconomy is sufficiently high. Otherwise, the platform's equilibrium information sharing strategy is partial information sharing. Finally, we characterize the comparative statics of the platform's optimal information accuracy decision with respect to key model parameters. Specifically, we show that the probability of carrier freight rejection is a positive factor that encourages the platform to increase the optimal information accuracy.

By analyzing the extended model that incorporates supply chain competition, we find that the platform's equilibrium information sharing comes in three distinct formats: (a) symmetric partial information sharing (i.e., both supply chains both adopt partial information sharing), (b) asymmetric mixed information sharing (i.e., one supply chain adopts full information sharing, while the other adopts partial information sharing), and (c) symmetric full information sharing (i.e., both supply chains adopt full information sharing). As the manufacturer's production diseconomy increases, the platform gradually switches the equilibrium information sharing formats from (a) to (c), indicating a shift towards more comprehensive information sharing across the supply chains. Furthermore, we also characterize the platform's optimal information accuracy decision. Notably, the optimal information accuracy decision exhibits a piecewise form as the platform switches equilibrium information sharing formats. We find that the monotonic behavior of the platform's optimal accuracy decision with respect to the probability of carrier freight rejection continues to hold in the presence of supply chain competition. Interestingly we unveil two-fold impacts of supply chain competition on the platform's optimal accuracy decision. Firstly, as the competition intensifies, the platform experiences disruptive improvements in its information accuracy. This is reflected by two upward jumps in the platform's optimal information accuracy as it transitions equilibrium information sharing formats from (a) to (c). Secondly, under every equilibrium information sharing format, the platform's information accuracy decision decreases as the competition intensity increases.

1.3. Contributions and Implications

This paper contributes to the literature by developing new implications to academics and practitioners regarding the informational roles of digital freight platforms, the management of carrier freight rejection, and information sharing in supply chain logistics, as follows:

1. Existing studies have primarily focused on discussing the role of digital freight platforms in matching freight demand and supply (Miller et al. 2020, Li et al. 2020, Zhou and Wan 2022). However, the literature rarely studies the platform's role of information sharing in improving supply chain operations. This work is the first to examine digital freight platforms' information sharing to firms in supply chains subject to carrier freight rejection. Our results show that digital freight platforms' information sharing enhances firms' responsiveness to carrier freight rejection and enables the platforms to effectively exploit the business value of its private information.
2. Noticing the negative effect of carrier freight rejection, the literature (e.g., Acocella et al. (2022), Scott et al. (2017)) has proposed a few solutions (e.g., flexible freight contracts) for managing carrier freight rejection from the perspective of suppressing the probability of carrier freight rejection. Unlike the literature, this paper introduces a novel approach by focusing on improving firms' responsiveness to carrier freight rejection through information sharing. Interestingly, we find that as the probability of carrier freight rejection increases, the new solution of information sharing leads to higher payoffs for shippers, as they are able to better respond to this phenomenon. Furthermore, we also examine the interaction between the existing solutions and our new solution and observe a *negative spillover effect* of digital freight platforms' information sharing on the effectiveness of the existing solutions.
3. Previous studies (e.g., Ha et al. (2011, 2017, 2022), Liu et al. (2021)) on information sharing have primarily focused on intra-supply-chain information sharing or information sharing by retail platforms to individual firms (e.g., retailers or suppliers). This paper extends the prior studies by considering a new context of information sharing between digital freight platforms and firms in supply chains, and discusses the platforms' strategic choices in information sharing strategies and information accuracy. Based on the new context, we extend the analysis of the

effect of information sharing on digital freight platforms, and find that double marginalization effect and the manufacturer's production diseconomy continue to play important roles in shaping the platform's equilibrium information sharing strategy. Interestingly, our results show that the platform's equilibrium information sharing formats for competing supply chains can be asymmetric mixed information sharing, which differs from the prior result (that only symmetric information sharing formats arise) in the literature (Ha et al. 2011). We also reveal the extraordinary impact of supply chain competition on digital freight platforms' switch of equilibrium information formats and optimal information accuracy decision.

2. Literature Review

This paper is related to three streams of literature: (i) digital freight platforms, (ii) freight operations considering carrier freight rejection, and (iii) supply chain information sharing.

Digital Freight Platforms. In recent years, digital freight (brokerage) platforms, also known as online freight exchange platforms, have garnered increasing interest from operations management researchers. Supported by advanced information and communication technologies (such as mobile apps, the Internet of things, and electronic data interchange), these platforms enable shippers in supply chains to timely locate for-hire (or private) carriers from the spot freight market, especially when they are rejected by their contracted carriers. Most of the existing literature delves into the fundamental roles of digital freight platforms in addressing the matching or assignment problem, as well as how to improve the platform's performance of matching and assignment (Caplice 2007, Min and Kang 2021, Li et al. 2020, Cao et al. 2022). For example, Miller et al. (2020) studies truck routing problems for digital freight platforms, assuming visibility of network-wide demand and supply information. Specifically, they model the routing problems as a Markov decision process, taking into account multiple factors such as the probability of winning a load, future profitability, and the bidding order priority among possible load options. Li et al. (2020) study the problem of digital freight platforms jointly optimizing matching and pricing strategies for delivering to multiple retailers, and demonstrate the effectiveness of their proposed matching and pricing policy using empirical data from a famous freight platform in China. Guo et al. (2022) design double auction mechanisms for digital freight platforms to elicit hidden information from the agents, such as their heterogeneous transaction costs and asymmetric demand information, to improve the matching of shipper demand and carrier supply. In addition to these theoretical studies, Zhou and Wan (2022) conducts an empirical study to examine the impact of digital freight platforms on the profitability and stock performance of incumbent road freight logistics companies, and find that only large trucking companies have significant positive profitability changes.

In supply chain logistics practice, digital freight platforms also play an informational role of sharing information to firms within the supply chains to improve operations (Pyzyk 2021). Yet, this aspect is seldom addressed in existing literature. This paper is among the few that investigates the impact of information sharing via digital freight platforms on supply chain operations in response to freight carrier rejection. This paper further discusses the strategic problems that digital freight platforms face when deciding on information sharing strategies and optimizing information accuracy. Our result complements the literature by giving insight into the conditions under which digital freight platforms implement various equilibrium information sharing strategies in both single and competing supply chains. Furthermore, we unveil the impact of the probability of carrier freight rejection—a key parameter in trucking industry—on the optimal information accuracy of digital freight platforms.

Freight Operations Considering Carrier Freight Rejection. There is a large body of operations management literature addressing freight operations in supply chain logistics, examining the interplay between freight operations and classical retail, inventory, and production operations (Lu et al. 2017, Stenius et al. 2018, Lu et al. 2020, Boada-Collado et al. 2020). It's worth noting that most of these studies are based on the assumption that shippers can secure freight rates by entering into long-term contracts with contracted carriers. However, since these long-term freight contracts lack legally binding obligations, shippers often encounter carrier freight rejection in a tight freight market, resulting in high operational costs for the entire supply chain (Scott et al. 2017, Aemireddy and Yuan 2019, Caplice 2021). Moreover, as freight market conditions grow increasingly uncertain and complex, the negative impact of carrier freight rejection can no longer be ignored. Consequently, a few researchers have started to explore freight operations considering carrier freight rejection. For example, Tsai et al. (2011) propose the use of derivative contracts in trucking as a means to hedge against uncertainty in transportation capacity and cost. Scott et al. (2017) carry out an empirical study to examine key operational and economic factors that drive and deter carrier freight rejection. In particular, they suggest implementing a flexible freight pricing mechanism to mitigate carrier freight rejection. Acocella et al. (2022) propose a market-based freight contract, which dynamically updates the freight price between shippers and carriers in order to minimize the probability of carrier freight rejection.

This paper also belongs to the literature on freight operations considering freight carrier rejection. Unlike the extant studies, we consider a new solution of improving supply chains' responsiveness to freight carrier rejection via digital freight platforms' information sharing. Our results demonstrate the effectiveness of this solution by quantifying the positive effect of information sharing on shippers (i.e., the retailer) relative to the benchmark of no information sharing. Interestingly, the result also shows that shippers' payoffs could increase as the probability of carrier freight rejection increases under digital freight platforms' information sharing, which contradicts to the conventional wisdom that probability of carrier freight rejection hurts shippers in the literature. We also examine the interaction between the existing solutions of suppressing probability of carrier freight rejection and our solution of information sharing, and find that the existing solution can hurt shippers in the presence of information sharing.

Supply Chain Information Sharing. Information sharing in supply chains is a widely explored topic in the operations management community. Over the past decades, numerous papers have addressed a variety of issues related to information sharing, especially in the context of demand information sharing (Lee et al. 2000, Li 2002, Ha et al. 2011, Shang et al. 2016, Ha et al. 2017, Shi et al. 2021). Notably, Ha et al. (2011) is a pioneering work that studies the impact of downstream firms' demand information sharing on upstream firms within competing supply chains. Recently, the emergence of platforms possessing superior information resources compared to individual firms in supply chains has prompted some researchers to investigate issues related to platform information sharing. For example, Liu et al. (2021) considers a retail platform's information sharing problem in which the platform possesses superior demand information and controls the information accuracy level when sharing it to competing sellers. Based on the privacy and fairness constraints, they explore different formats for the platform's information sharing, namely, asymmetric full/partial sharing and symmetric full/individual sharing. They find that the platform's optimal strategy is to select a subset of sellers and truthfully share information with them under the asymmetric sharing format, while under the symmetric sharing format, the platform is incentivized to reduce the accuracy of the shared information. Tsunoda and Zennyo (2021) considers a supplier's multi-channel problem of selling its products through both an online platform and an offline retailer, where the platform can share its superior demand information to the supplier. They demonstrate that the platform's information sharing capability makes the agency model more likely to be adopted. Ha et al. (2022) develops a multistage game-theoretic model to study the impact of retail platforms' information sharing on an upstream manufacturer's encroachment decision and, more generally, the manufacturer's channel choice decision. Their analysis reveals a complementary relationship between the platform's information sharing and the manufacturer's encroachment.

This paper also falls into the research stream on platform's information sharing, and contributes to the literature by discussing a new context of digital freight platform's information sharing with firms in supply chains. More specifically, our paper has two differentiating features. First, most of the prior studies address either intra-supply-chain information sharing or vertical information sharing from platform to individual firms. However, digital freight platforms' information sharing combines both platform-to-supply-chain and intra-supply-chain information sharing together. In some sense, our results on the operational effect of digital freight platforms' information sharing generalize the prior result by Ha et al. (2011). Second, only a small proportion of the existing studies consider the platform's strategic information accuracy decision. The work of Liu et al. (2021) is an exception, treating the retail platform's information accuracy decision as a binary variable of whether to add additional noise to original freight information or not. Unlike Liu et al. (2021), we model the digital freight platform's information accuracy decision as a continuous variable. By doing so, we are able to gain deeper insights into how the probability of carrier freight rejection and supply chain competition influence the platform's optimal decision regarding information accuracy.

3. Model

We consider a model consisting of an digital freight brokerage platform (simply referred to as "the platform") and a supply chain. In the supply chain, a retailer ("she") procures goods from a manufacturer ("he") at a wholesale price w. Following the literature on information sharing (Ha et al. 2011, 2017, Shang et al. 2016, Liu et al. 2021), we assume that the retailer sells the goods to a Cournot-type market of customers, and has the market power to shape the retail price p of the goods by adjusting the retail quantity q. Specifically, the retail price is given by $p = u - q$, where u is the market size.

The retailer, in addition to procuring goods from the manufacturer, also requires transportation services to move the procured goods. Following established practices in supply chain logistics (Caplice 2007, Scott et al. 2017, Acocella et al. 2022, Scott 2015, Caplice 2021), we assume that the retailer can secure transportation under a long-term freight contract with a contracted carrier. Under this arrangement, the retailer pays a contract freight rate r_c to the contracted carrier for the transportation of the procured goods. Because the focus of our paper is *not* the game between the retailer and the contracted carrier, r_c is assumed to be an exogenous parameter in our model. The retailer also faces the possibility of carrier freight rejection, which depends on uncertain freight market conditions. In our model, there are two possible freight market conditions: either *tight* or *soft*. When the freight market is soft, carrier freight rejection does not occur, and the retailer pays the fixed rate r_c to the contracted carrier for hauling the procured goods per unit. When the freight market is tight, carrier freight rejection can occur with probability δ, referred to as the "probability of carrier freight rejection," which satisfies $\delta \in [\underline{\delta}, 1]$ (where $\underline{\delta} > 0$ is a lower bound of δ). If the freight rejection occurs, the retailer turns to the platform and seeks an alternative for-hire carrier. In this case, the retailer pays spot freight rate $r_c + \xi$, where $\xi > 0$ is the spot freight premium, to the for-hire carrier for hauling the procured goods per unit. Additionally, the retailer pays a brokerage fee ρ to the platform for matching the freight capacity per unit. In practice, the spot freight premium is determined by the digital freight brokerage platform's matching of spot freight demand and supply using sophisticated algorithms (Miller et al. 2020, Li et al. 2020). Since this paper does not address the platform's matching issues, the parameter ξ is exogenous and represents the average spot freight premium in our model.

Every player has public prior information about the freight market conditions as follows. The prior probability of a tight freight market is θ, while that of soft freight market is $1-\theta$. However, the platform possesses additional private information Υ about the freight market conditions. Specifically, $\Upsilon = 1$ (resp., $\Upsilon = 0$) is an informative indicator of a tight (resp., soft) freight market as follows:

$$\mathbb{P}\{\Upsilon = 1 \,|\, \text{tight}\} = \vartheta, \qquad \mathbb{P}\{\Upsilon = 0 \,|\, \text{tight}\} = 1-\vartheta,$$

$$\mathbb{P}\{\Upsilon = 1 \,|\, \text{soft}\} = 1-\vartheta, \qquad \mathbb{P}\{\Upsilon = 0 \,|\, \text{soft}\} = \vartheta,$$

where $\vartheta \geq 1/2$ to ensure the informativeness of the signal Υ. Following the literature on information accuracy (e.g., Colombo and Femminis (2008), Kurtuluş et al. (2012), Han and Yang (2013)), we measure the accuracy a of the private information Υ by the reciprocal of the variance of the signal Υ conditioned on the freight market conditions (either tight or soft) as follows:

$$a := \frac{1}{\text{Var}[\Upsilon \,|\, \text{tight}]} = \frac{1}{\text{Var}[\Upsilon \,|\, \text{soft}]} = \frac{1}{\vartheta(1-\vartheta)}, \quad \vartheta \geq \frac{1}{2}.$$

Furthermore, the platform is able to improve the accuracy a of the private information by improving its data analytics techniques. However, this improvement comes at an information cost $w(a)$ that is convexly increasing in the accuracy level a.

With its private information Υ, the platform has three possible information sharing arrangements for the firms in the supply chain:

- No Information Sharing (`N`): The platform does not share its private information Υ with any firms in the supply chain.
- Partial Information Sharing (`P`): The platform shares its private information Υ with the retailer only.
- Full Information Sharing (`F`): The platform shares its private information Υ with both the retailer and the manufacturer.

Throughout the paper, we use the no information sharing arrangement as the benchmark against which we assess the impact of the platform's information sharing on each player.

All the players engage in a multi-stage game as follows. Initially, the platform makes two-fold strategic information decisions by choosing the accuracy a of its private information and the information arrangement $\mathtt{Y} \in \{\mathtt{N}, \mathtt{P}, \mathtt{F}\}$ for the supply chain. Given the platform's strategic information decisions, every player's operational decisions proceeds sequentially as follows. First, the manufacturer announces the wholesale price w. Second, the platform determines the brokerage fee ρ.

Third, the retailer, anticipating carrier freight rejection depending on the uncertain freight market conditions, decides the order quantity q. The assumption that the manufacturer determines the wholesale price prior to the platform's brokerage fee is aligned with supply chain logistics practice. That is, retailing firms use their wholesale contracts with upstream suppliers as the basis for their transportation procurement contracts with digital freight brokerage platforms (Inderfurth et al. 2013, Boada-Collado et al. 2020). Furthermore, we assume the platform is able to observe the manufacturer's wholesale price when deciding its brokerage fee. This assumption often appears in the literature (e.g., Li (2002)) by the fact that the retailer's order quantity is a monotonically increasing function of the wholesale price, allowing the platform to infer the wholesale price. Finally, we assume that the retailer decides the order quantity prior to carrier freight rejection, aligning with the practical transportation procurement process where shippers have to plan their loads considering the risks of carrier freight rejection in advance (Caplice 2021, Acocella et al. 2022).

For ease of exposition, we follow the literature on information sharing (e.g., Ha et al. (2011, 2017)) by not considering the other linear variable costs for each player. Instead, we focus specifically on the manufacturer's quadratic production cost $cq^2/2$ in the presence of production diseconomy, where c captures the degree of production diseconomy. To ensure that every player's interior solution is optimal, we also assume $u > r_c + \xi\delta\theta$. In this paper, we let $\mathbb{E}[X]$ and $\mathrm{Var}[X]$ denote the expectation and variance of a random variable X. Table 1 provides a summary of the main notation used in this paper along with their corresponding meanings.

Table 1 Summary of Notation

Notation	Meaning
Parameters:	
c	Coefficient of manufacturer's production diseconomy
r_c	Contracted freight rate
ξ	Spot freight rate premium
δ	Probability that the retailer's tender request is rejected by her contracted carrier
θ	Prior probability of tight freight market
ϑ	Prior probability of $\Upsilon = 1/\Upsilon = 0$ in tight/soft freight market
u	Potential customer demand
Υ	Platform's private signal about freight market conditions
Decision variables:	
q	Retailer's order quantity
w	Manufacturer's wholesale price
ρ	Platform's brokerage fee

4. Information Sharing to a Single Supply Chain

We employ a backward induction approach to solve the multistage game. First, we derive the equilibrium operational decisions of each player given the platform's strategic information arrangements. Second, we characterize platform's strategic information decisions by assessing the effect of the platform's information sharing on each player.

As a preparatory step, we derive the expression for the retailer's expected freight rate conditioned on the platform's private information Υ. When $\Upsilon = 1$, the posterior probability of a tight freight market is given by

$$\mathbb{P}\{\text{tight} \,|\, \Upsilon = 1\} = \frac{\theta\vartheta}{\theta\vartheta + (1-\theta)(1-\vartheta)}.$$

Similarly, when $\Upsilon = 0$, the posterior probability of a tight freight market is

$$\mathbb{P}\{\text{tight} \,|\, \Upsilon = 0\} = \frac{\theta(1-\vartheta)}{\theta(1-\vartheta) + (1-\theta)\vartheta}.$$

We define $G(\Upsilon) := \mathbb{P}\{\text{tight} \,|\, \Upsilon\}$ to be the posterior probability of a tight freight market conditioned on Υ, which is given by

$$G(\Upsilon) = \frac{\theta\big((2\vartheta - 1)\Upsilon - \vartheta + 1\big)}{\theta + \vartheta - 2\theta\vartheta + (2\theta - 1)(2\vartheta - 1)\Upsilon}. \tag{1}$$

Thus, the posterior probability of a soft freight market is given by $1 - G(\Upsilon)$. Recall that in a soft freight market, the retailer's freight cost rate is r_c. However, in a tight freight market, the retailer's expected freight cost rate is $r_c(1-\delta) + (r_c + \xi + \rho)\delta$ due to carrier freight rejection. Therefore, the retailer's expected freight rate conditioned on Υ is

$$r_c\big(1 - G(\Upsilon)\big) + \big(r_c(1-\delta) + (r_c + \xi + \rho)\delta\big)G(\Upsilon) = r_c + (\rho + \xi)\delta G(\Upsilon).$$

It follows that the retailer's expected freight cost rate based on the public prior information is

$$\mathbb{E}\big[r_c + (\rho + \xi)\delta G(\Upsilon)\big] = r_c + (\rho + \xi)\delta\theta.$$

4.1. Equilibrium Operational Decisions

No Information Sharing. Under the benchmark of no information sharing, both the retailer and the manufacturer do not have access to the platform's private information Υ. Given the manufacturer's wholesale price w and the platform's brokerage fee ρ, the retailer maximizes her expected profit based on the public prior information on the freight market conditions, i.e., $\mathbb{E}\left[(u - q - w - r_c - (\rho + \xi)\delta G(\Upsilon))\, q\right]$, with the following order quantity:

$$\bar{q}(w, \rho) = \frac{1}{2}\left(u - r_c - (\rho + \xi)\delta\theta - w\right).$$

Given the retailer's order quantity $\bar{q}(\cdot)$, the platform maximizes its expected revenue from the retailer conditional on Υ, i.e., $\mathbb{E}\left[\bar{q}(w,\rho)\rho\delta G(\Upsilon)\,|\,\Upsilon\right]$, by setting the following brokerage fee:

$$\bar{\rho}(w) = \frac{u - r_c - \delta\xi\theta - w}{2\delta\theta}.$$

We observe that even though the platform has the private information Υ, it is unable to utilize it to adjust its brokerage fee. This is because the retailer's order quantity $\bar{q}(\cdot)$ is independent of the platform's private information.

Similar to the retailer, the manufacturer maximizes his expected profit based on the public prior information, i.e., $\mathbb{E}\left[\bar{q}(w,\bar{\rho}(w))w - \frac{c}{2}[\bar{q}(w,\bar{\rho}(w))]^2\right]$, using the following wholesale price:

$$w^{\mathtt{N}} = \frac{(c+4)\,(u - r_c - \delta\xi\theta)}{c+8}. \tag{2}$$

Consequently, we obtain the supply chain's equilibrium retail quantity $q^{\mathtt{N}} := \bar{q}(w^{\mathtt{N}}, \bar{\rho}(w^{\mathtt{N}}))$ and the platform's equilibrium brokerage fee $\rho^{\mathtt{N}} := \bar{\rho}(w^{\mathtt{N}})$ under the benchmark of no information sharing, and are given as follows:

$$\begin{aligned} q^{\mathtt{N}} &= \frac{u - r_c}{c+8} - \frac{\delta\xi\theta}{c+8}, \\ \rho^{\mathtt{N}} &= \frac{2(u - r_c)}{(c+8)\delta}\frac{1}{\theta} - \frac{2\xi}{c+8}. \end{aligned} \tag{3}$$

It is worth noting that both $q^{\mathtt{N}}$ and $\rho^{\mathtt{N}}$ are decreasing in the probability δ of carrier freight rejection.

Let $\Pi_R^{\mathtt{N}}$, $\Pi_M^{\mathtt{N}}$, and $\Pi_P^{\mathtt{N}}$ denote the retailer's, manufacturer's, and the platform's ex-ante payoffs under the benchmark, respectively. After some calculations, we conclude that:

$$\Pi_R^{\mathtt{N}} = \frac{(u - r_c - \delta\xi\theta)^2}{(c+8)^2}, \quad \Pi_M^{\mathtt{N}} = \frac{(u - r_c - \delta\xi\theta)^2}{2(c+8)}, \quad \Pi_P^{\mathtt{N}} = \frac{2\,(u - r_c - \delta\xi\theta)^2}{(c+8)^2}, \tag{4}$$

which are all decreasing in δ because the supply chain's equilibrium retail quantity $q^{\mathtt{N}}$ and the platform's equilibrium brokerage fee $\rho^{\mathtt{N}}$ are both decreasing in δ. In particular, the negative effect of δ on the retailer is consistent with the conventional wisdom in the literature that the probability of carrier freight rejection hurts shippers in supply chains (Scott 2015, Caplice 2021).

Partial Information Sharing. Under partial information sharing, the retailer observes the platform's private information and maximizes her expected profit conditional on Υ, i.e., $\mathbb{E}\left[(u - q - w - r_c - (\rho + \xi)\delta G(\Upsilon))\,q\,|\,\Upsilon\right]$, with the following order quantity:

$$\breve{q}(w,\rho) = \frac{1}{2}\left(u - r_c - (\rho + \xi)\delta G(\Upsilon) - w\right).$$

Given the retailer's order quantity $\breve{q}(\cdot)$, the platform maximizes its expected revenue from the retailer conditional on Υ, i.e., $\mathbb{E}\left[\breve{q}(w,\rho)\rho\,\delta G(\Upsilon)\,|\,\Upsilon\right]$, by setting the following brokerage fee:

$$\breve{\rho}(w) = \frac{u - r_c - \delta\xi G(\Upsilon) - w}{2\delta G(\Upsilon)}.$$

By comparing $\bar{\rho}(\cdot)$ to $\breve{\rho}(\cdot)$ we find that the platform is able to utilize its private information Υ to adjust the brokerage fee in response to carrier freight rejection, as the retailer's order quantity $\breve{q}(\cdot)$ captures Υ. This observation highlights how information sharing enables the platform to effectively exploit its private information.

Unlike the retailer, the manufacturer does not observe Υ and maximizes his expected profit based on the public prior information, i.e., $\mathbb{E}\left[\breve{q}(w,\breve{\rho}(w))w-\frac{c}{2}[\breve{q}(w,\breve{\rho}(w))]^2\right]$, using the following wholesale price:

$$w^{\mathtt{P}}=w^{\mathtt{N}}=\frac{(c+4)\,(u-r_c-\delta\xi\theta)}{c+8}.$$

Using these results, we obtain the supply chain's equilibrium retail quantity $q^{\mathtt{P}}:=\breve{q}(w^{\mathtt{P}},\breve{\rho}(w^{\mathtt{P}}))$ and the platform's equilibrium brokerage fee $\rho^{\mathtt{P}}:=\breve{\rho}(w^{\mathtt{P}})$ under partial information sharing as follows:

$$\begin{aligned} q^{\mathtt{P}} &= \frac{u-r_c}{c+8}+\frac{(c+4)\delta\xi\theta}{4(c+8)}-\frac{\delta\xi}{4}G(\Upsilon),\\ \rho^{\mathtt{P}} &= \frac{4(u-r_c)+(c+4)\delta\xi\theta}{2(c+8)\delta}\frac{1}{G(\Upsilon)}-\frac{\xi}{2}. \end{aligned} \tag{5}$$

Full Information Sharing. Under full information sharing, the retailer's order quantity and the platform's brokerage fee continue to follow $\breve{q}(\cdot)$ and $\breve{\rho}(\cdot)$, respectively. Furthermore, the manufacturer maximizes his expected profit conditional on the platform's private information Υ, i.e., $\mathbb{E}\left[\breve{q}(w,\breve{\rho}(w))w-\frac{c}{2}[\breve{q}(w,\breve{\rho}(w))]^2\,|\,\Upsilon\right]$, using the following wholesale price:

$$w^{\mathtt{F}}=\frac{(c+4)\,(u-r_c-\delta\xi G(\Upsilon))}{c+8}.$$

The supply chain's equilibrium retail quantity $q^{\mathtt{F}}:=\breve{q}(w^{\mathtt{F}},\breve{\rho}(w^{\mathtt{F}}))$ and the platform's equilibrium brokerage fee $\rho^{\mathtt{F}}:=\breve{\rho}(w^{\mathtt{F}})$ under full information sharing are given by:

$$\begin{aligned} q^{\mathtt{F}} &= \frac{u-r_c}{c+8}-\frac{\delta\xi}{c+8}G(\Upsilon),\\ \rho^{\mathtt{F}} &= \frac{2(u-r_c)}{(c+8)\delta}\frac{1}{G(\Upsilon)}-\frac{2\xi}{c+8}. \end{aligned} \tag{6}$$

Note that we can assess the responsiveness (or equivalently the variability) of the supply chain's and the platform's equilibrium decisions to carrier freight rejection due to Υ under partial and full information sharing by examining the variances $\operatorname{Var} q^{\mathtt{Y}}$ and $\operatorname{Var}\rho^{\mathtt{Y}}$, where $\mathtt{Y}\in\{\mathtt{P},\mathtt{F}\}$. From equations (5) and (6) we derive the following expressions:

$$\begin{aligned} \operatorname{Var}[q^{\mathtt{P}}]-\operatorname{Var}[q^{\mathtt{F}}] &= \frac{(c+4)(c+12)\delta^2\xi^2}{16(c+8)^2}\operatorname{Var}[G(\Upsilon)]>0,\\ \operatorname{Var}[\rho^{\mathtt{P}}]-\operatorname{Var}[\rho^{\mathtt{F}}] &= \frac{(c+4)\big((c+4)\delta\xi\theta+8(u-r_c)\big)\theta\xi}{4(c+8)^2\delta}\operatorname{Var}\left[\frac{1}{G(\Upsilon)}\right]>0. \end{aligned}$$

From these inequalities we have the following useful observation: Relative to partial information sharing, full information sharing reduces the responsiveness of the supply chain's and platform's equilibrium decisions to carrier freight rejection. This result is caused by the well-known *double marginalization effect* (DME) in supply chains (Ha et al. 2011, 2017). That is, the manufacturer's adjustment in the wholesale price works in the opposite direction to the retailer's and platform's respective adjustments in the order quantity and brokerage fee.

4.2. Effect of Platform's Information Sharing

Let $\Pi_R^{\mathtt{Y}}$, $\Pi_M^{\mathtt{Y}}$, and $\Pi_P^{\mathtt{Y}}$ denote the retailer's, manufacturer's, and the platform's ex-ante payoffs, respectively, under information sharing strategy $\mathtt{Y} \in \{\mathtt{P}, \mathtt{F}\}$. By defining $\eta := \mathbb{E}[G(\Upsilon)^2] - \mathbb{E}[G(\Upsilon)]^2 = \mathbb{E}[G(\Upsilon)^2] - \theta^2$ as the variance of $G(\Upsilon)$, we have:

$$\begin{aligned} \Pi_R^{\mathtt{P}} &= \Pi_R^{\mathtt{N}} + \frac{\eta\delta^2\xi^2}{16}, \quad & \Pi_M^{\mathtt{P}} &= \Pi_M^{\mathtt{N}} - \frac{c\eta\delta^2\xi^2}{32}, \quad & \Pi_P^{\mathtt{P}} &= \Pi_P^{\mathtt{N}} + \frac{\eta\delta^2\xi^2}{8}, \\ \Pi_R^{\mathtt{F}} &= \Pi_R^{\mathtt{N}} + \frac{\eta\delta^2\xi^2}{(c+8)^2}, \quad & \Pi_M^{\mathtt{F}} &= \Pi_M^{\mathtt{N}} + \frac{\eta\delta^2\xi^2}{2(c+8)}, \quad & \Pi_P^{\mathtt{F}} &= \Pi_P^{\mathtt{N}} + \frac{2\eta\delta^2\xi^2}{(c+8)^2}. \end{aligned} \tag{7}$$

Based on (7), we assess the effect of the platform's information sharing strategies $\mathtt{Y} \in \{\mathtt{P}, \mathtt{F}\}$ on every player relative to the benchmark of no information sharing by examining the quantities $\Pi_R^{\mathtt{Y}} - \Pi_R^{\mathtt{N}}$, $\Pi_M^{\mathtt{Y}} - \Pi_M^{\mathtt{N}}$, and $\Pi_P^{\mathtt{Y}} - \Pi_P^{\mathtt{N}}$. Moreover, we can compare the effects of partial and full information sharing on every player by examining $\Pi_R^{\mathtt{F}} - \Pi_R^{\mathtt{P}}$, $\Pi_M^{\mathtt{F}} - \Pi_M^{\mathtt{P}}$, and $\Pi_P^{\mathtt{F}} - \Pi_P^{\mathtt{P}}$.

PROPOSITION 1. *Relative to the benchmark of no information sharing,*

(a) Partial information sharing benefits the retailer and the platform, but hurts the manufacturer.

(b) Full information sharing benefits the retailer, the manufacturer, and the platform.

Moreover, relative to partial information sharing,

(c) Full information sharing hurts the retailer and the platform, but benefits the manufacturer.

Proof. All proofs are relegated to the Appendix. □

Parts (a) and (b) of Proposition 1 can be interpreted as follows. On the one hand, both partial and full information sharing benefit the retailer and the platform (i.e., $\Pi_R^{\mathtt{Y}} > \Pi_R^{\mathtt{N}}$ and $\Pi_P^{\mathtt{Y}} > \Pi_P^{\mathtt{N}}$ for $\mathtt{Y} \in \{\mathtt{P}, \mathtt{F}\}$) because information sharing improves the retailer's adjustment of her order quantity in response to carrier freight rejection, and enables the platform to exploit business value from its private information. On the other hand, the platform's information sharing makes the retailer's order quantity become variable due to Υ, and does not necessarily benefit the manufacturer. Specifically, under partial information sharing, the manufacturer is unable to observe Υ and adjust the wholesale price, resulting in increased production costs due to the production diseconomy. However, under full information sharing, the manufacturer observes Υ and can benefit by adjusting the wholesale price accordingly. Part (c) of Proposition 1 further shows that full information sharing hurts the retailer and the platform relative to partial information sharing because of the aforementioned DME. It is worth mentioning that part (c) also extends the prior findings in the literature on information sharing by showing that platform's information sharing also leads to DME on itself.

The primary implications of Proposition 1 are twofold. First, the benchmark strategy of no information sharing is dominated by the platform's information sharing strategies (either partial or full), which confirms the economic incentives behind the platform's information sharing. Second, the manufacture is incentivized to induce full information sharing by offering side payments to the retailer and the platform to offset their losses.

4.3. Platform's Strategic Information Decisions

Proposition 1 has shown that the manufacturer will only induce full information sharing by offering side payments to both the retailer and the platform when the manufacturer's payoff surplus under full information sharing (rather than partial information sharing) is nonnegative. In particular, the manufacturer's payoff surplus, accounting for the side payments, is expressed by:

$$(\Pi_M^{\mathtt{F}} - \Pi_M^{\mathtt{P}}) \quad + \quad \underbrace{(\Pi_P^{\mathtt{F}} - \Pi_P^{\mathtt{P}}) + (\Pi_R^{\mathtt{F}} - \Pi_R^{\mathtt{P}})}_{\text{Side payments to the platform and retailer}} \quad .$$

Based on these findings, we conclude:

Proposition 2. *In single supply chain,*

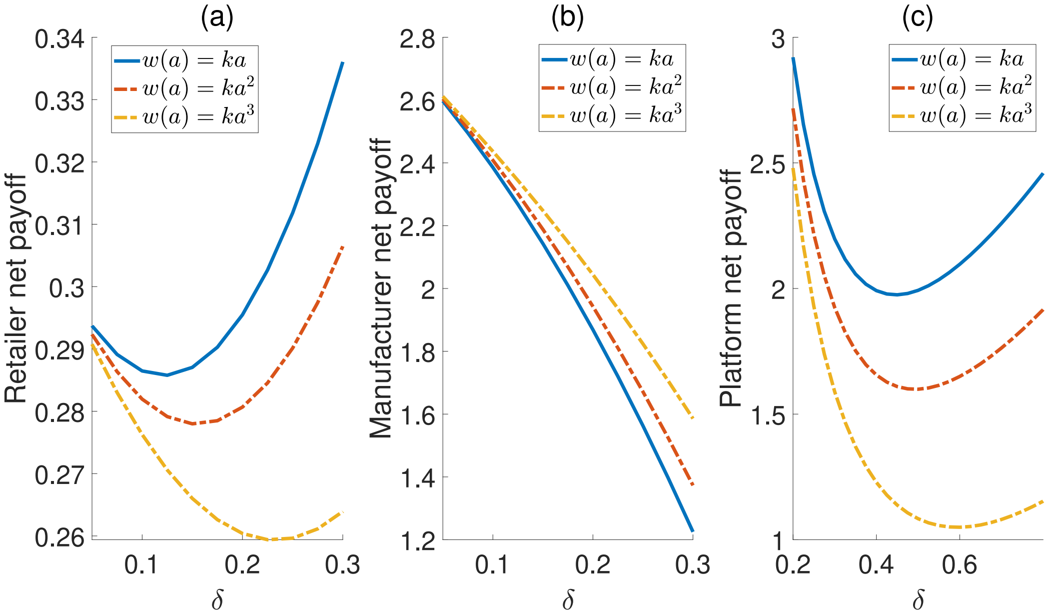
(a) If $c \geq 4$, then full information sharing is induced under the manufacturer's side payments to the retailer and the platform; otherwise, partial information sharing is adopted.

(b) Accounting for the possible side payments, the platform's equilibrium gross payoff under either partial or full information sharing is

$$\frac{2\left(u - r_c - \delta\xi\theta\right)^2}{(c+8)^2} + \frac{\delta^2\xi^2}{8}\eta. \tag{8}$$

Part (a) of Proposition 2 characterizes that platform's equilibrium information sharing strategy (see Figure 2(a)) by highlighting that full information sharing would be induced when the manufacturer's production diseconomy is sufficiently large (i.e., $c \geq 4$). This result can be explained as follows. As the manufacturer's production diseconomy becomes large (i.e., as c increases), the manufacturer can reduce more production costs under full information sharing compared to partial information sharing, allowing the manufacturer to cover the side payments to the retailer and the platform. Part (b) shows the platform's gross payoff, taking into account the manufacturer's possible side payments. Specifically, the terms $\frac{2(u-r_c-\delta\xi\theta)^2}{(c+8)^2}$ and $\frac{\delta^2\xi^2}{8}\eta$ in (8) stem from the public prior information and the platform's private information about freight market conditions, respectively.

Figure 2 The platform's strategic information decisions for single supply chain: Figures (a)–(c) illustrate the retailer's, manufacturer's, and platform's net payoffs under the platform's optimal information accuracy decision for different values of δ, when the cost function $w(a)$ has linear, quadratic, and cubic forms.



Based on the platform's equilibrium gross payoff, we next explore the platform's strategic choice in the accuracy a of its private information. Recalling the definition of η, we can express η in terms of a as follows:

$$\eta = \mathbb{E}\left[G(\Upsilon)^2\right] - \theta^2 = \frac{(2\vartheta-1)^2(1-\theta)^2\theta^2}{(2\theta\vartheta+1-\theta-\vartheta)(\theta+\vartheta-2\theta\vartheta)} = \frac{(a-4)(\theta-1)^2\theta^2}{(a-4)(1-\theta)\theta+1}, \quad a \geq 4, \tag{9}$$

where the third equality follows from the definition of $a = \frac{1}{(1-\vartheta)\vartheta}$. Therefore, the platform's problem of maximizing its net payoff (i.e., the platform's gross payoff minus the information cost $w(a)$) by optimizing over the accuracy a is given as follows:

$$\max_{a\geq 4}\left\{\frac{2\left(u-r_c-\delta\xi\theta\right)^2}{(c+8)^2}+\frac{\delta^2\xi^2}{8}\eta(a)-w(a)\right\}. \tag{10}$$

In (10), the term $\eta(a)$ captures the platform's responsiveness to carrier freight rejection. In particular, it is concavely increasing in a, implying a diminishing return of improving the platform's responsiveness by increasing the information accuracy. The term $\frac{\delta^2\xi^2}{8}$ represents the marginal value of the platform's information sharing. Moreover, by the convexity of $w(a)$, the objective function of (10) is concave, leading to the uniqueness of the optimal information accuracy decision a^*.

Proposition 3. *For single supply chain, the platform's optimal information accuracy decision a^* has the following properties:*

(a) a^* *is increasing in* $\theta \in [0, \frac{1}{2}]$ *and is decreasing in* $\theta \in [\frac{1}{2}, 1]$.

(b) a^* *is increasing in* δ.

(c) When $w(a) = ka$ *with* $k > 0$*, the optimal information accuracy decision has the following closed form expression:*

$$a^* = 4 + \Big(\frac{\xi\delta}{\sqrt{8k}} - \frac{1}{(1-\theta)\theta}\Big)^+.$$

In this case, the retailer's and platform's net payoffs initially decrease and then increase in δ*, while the manufacturer's net payoff is decreasing in* δ.

Parts (a) and (b) of Proposition 3 present comparative statics of the platform's optimal accuracy a^*, for any general convex information cost function $w(a)$. More specifically, part (a) shows the behavior of a^* as the prior probability θ of a tight freight market increases. Note that the accuracy of the public information about a tight freight market, given by $\frac{1}{(1-\theta)\theta}$, decreases within the interval $\theta \in [0, \frac{1}{2}]$, and subsequently increases within $\theta \in [\frac{1}{2}, 1]$. Consequently, part (a) reveals a substitution relationship between the public information and the platform's private information. In other words, as the accuracy of the public information decreases, the platform is compelled to enhance the accuracy of its private information. Part (b) demonstrates the monotonicity of a^* with respect to the probability δ of carrier freight rejection. This means that the platform is incentivized to enhance the accuracy of its private information when the likelihood of supply chain disruptions, due to carrier freight rejection in a tight freight market, increases.

Part (c) provides a closed form expression for a^* when $w(a)$ is linear, and underscores the substitution relationship between the public information and the platform's private information. Specifically, when the accuracy of public information is sufficiently high where $\frac{1}{(1-\theta)\theta} \geq \frac{\delta\xi}{\sqrt{8k}}$, the platform has no incentive to improve the accuracy (i.e., $a^* \equiv 4$). Part (c) also characterizes the behavior of each player's net payoff (accounting for the possible side payments) under the platform's optimal information accuracy decision as δ increases. Interestingly, the non-monotonicity of the retailer's net payoff means that δ may benefit shippers in supply chain logistics, contradicting the conventional understanding of the negative role of δ in the literature (Scott 2015, Caplice 2021). This counterintuitive finding arises from the fact that under the platform's information sharing, a component of the retailer's payoff, namely $\frac{\delta^2\xi^2}{16}\eta(a^*(\delta))$, is increasing in δ. This component stems from the retailer's enhanced responsiveness to carrier freight rejection due to the platform's information sharing. Moreover, Figure 2 shows that this insight continues to hold even when the information cost $w(a)$ takes other forms, such as quadratic or cubic.

It is worth mentioning that the literature (e.g., Scott et al. (2017), Acocella et al. (2022)) has proposed a few solutions for managing carrier freight rejection by suppressing the probability δ

of carrier freight rejection, e.g., via flexible freight contracts. Unlike the existing literature, this paper provides a new solution by improving shippers' responsiveness to carrier freight rejection through the use of a digital freight platform's information sharing. The non-monotonic behavior of the retailer's net payoff also reveals the interaction between the existing solutions in the literature and our new solution. Interestingly, we find the existing solutions of suppressing δ may hurt the retailer under the platform's information sharing scheme. For example, in Figure 2(a), we see that if the original value of δ is 0.25, then the retailer experiences a decrease in her net payoff when δ is reduced to 0.15. This result reveals the existence of a negative spillover effect of digital freight platforms' information sharing on the effectiveness of the existing methods for managing carrier freight rejection.

5. Information Sharing to Competing Supply Chains

In this section, we consider the platform's information sharing in the presence of supply chain competition. Following the literature on information sharing (e.g., Ha et al. (2011, 2017), Liu et al. (2021)), we generalize the base model by considering two supply chains, each consisting of one retailer and one manufacturer. In particular, supply chain $i \in \{1, 2\}$ consists of a retailer i and a manufacturer i, and the two retailers engage in the Cournot competition. More specifically, retailer i's inverse demand function is given by $p_i = u - q_i - \gamma q_j$, where u is a constant, $0 < \gamma < 1$ is the competition intensity, and (q_i, q_j) are retailer i's and retailer j's retail quantities, respectively.

Every player has public prior information about freight market conditions, consistent with our base model, and the platform has the private information Υ. The sequence of events in the generalized model is as follows. First, the platform makes strategic information decisions by choosing the accuracy a of its private information Υ and information arrangements $\mathtt{Y}_i \in \{\mathtt{N}, \mathtt{P}, \mathtt{F}\}$ for each supply chain i. Second, in each supply chain i, the manufacturer i first proposes the wholesale price w_i. The platform then observes w_i and announces the brokerage fee ρ_i, and finally, retailer i determines the order quantity q_i. For analytical convenience, we assume that two supply chains have symmetric costs in the sense that the two retailers have the same contracted freight rate r_c and spot freight rate premium ξ, and both manufacturers have the same production cost $cq^2/2$. Moreover, in line with the literature (Ha et al. 2011, 2017, Liu et al. 2021), we assume that the decisions (w_i, ρ_i) in a focal supply chain i are not observable to retailer j and manufacturer j in the rival supply chain j, and, for privacy reasons, the platform is not allowed to share this information to them.

5.1. Equilibrium Operational Decisions

Next, we analyze the equilibrium operational decisions of every player under the platform's possible information arrangements for the two competing supply chains. It should be noted that in a focal supply chain i, both the retailer i and manufacturer i do not know rival supply chain j's retail quantity when making their own decisions. Following the literature (e.g., Ha et al. (2011, 2017)), we assume that the players from supply chain i form a common conjecture q_j about the rival supply chain j's retail quantity, and derive every player's equilibrium decision based on this common conjecture. We then use the notion of Bayesian Nash equilibrium to find the equilibrium retail quantities for the competing supply chains.

No Information Sharing. When the platform's information arrangement for supply chain i is no information sharing (i.e., $\mathtt{Y}_i = \mathtt{N}$), retailer i and manufacturer i make their own decisions based on public prior information about freight market conditions. Given the conjecture q_j of rival supply chain j's retail quantity, retailer i maximizes her expected profit only using public information about freight market conditions, i.e., $\mathbb{E}\left[(u - q_i - \gamma\, q_j - w_i - r_c - (\rho_i + \xi)\delta\, G(\Upsilon))\, q_i\right]$, with the following retail quantity:

$$\tilde{q}_i(w_i, \rho_i) = \frac{1}{2}\big(u - w_i - r_c - (\rho_i + \xi)\delta\theta - \gamma\,\mathbb{E}\left[q_j\right]\big).$$

The platform maximizes the expected revenue from retailer i conditional on Υ, i.e., $\mathbb{E}\left[\tilde{q}_i(w_i, \rho_i)\rho_i\delta G(\Upsilon) \,|\, \Upsilon\right]$, by setting the following brokerage fee:

$$\tilde{\rho}_i(w_i) = \frac{u - w_i - r_c - \xi\delta\theta - \gamma\,\mathbb{E}\left[q_j\right]}{2\delta\theta},$$

implying that the platform cannot fully utilize Υ to adjust its brokerage fee because $\tilde{q}_i(\cdot)$ is independent of Υ. Manufacturer i maximizes his expected profit only using public information about freight market conditions, i.e., $\mathbb{E}\left[\tilde{q}_i(w_i, \tilde{\rho}_i(w_i))w_i - \frac{c}{2}[\tilde{q}_i(w_i, \tilde{\rho}_i(w_i))]^2\right]$, using the following wholesale price:

$$w_i^{\mathtt{N}} = \frac{(c+4)\big(u - r_c - \xi\delta\theta - \gamma\,\mathbb{E}\left[q_j\right]\big)}{c+8}.$$

Then supply chain i's equilibrium retail quantity $q_i^{\mathtt{N}}(q_j) := \tilde{q}_i(w_i^{\mathtt{N}}, \tilde{\rho}_i(w_i^{\mathtt{N}}))$ under no information sharing is given as follows:

$$q_i^{\mathtt{N}}(q_j) = \frac{u - r_c}{c+8} - \frac{\xi\delta\theta}{c+8} - \frac{\gamma\,\mathbb{E}\left[q_j\right]}{c+8}. \tag{11}$$

Partial Information Sharing. When the platform's information arrangement for supply chain i is partial information sharing (i.e., $\mathtt{Y}_i = \mathtt{P}$), retailer i observes Υ and maximizes her expected profit based on the conjecture q_j of rival supply chain j's retail quantity, i.e., $\mathbb{E}\left[(u, -q_i - \gamma\, q_j - w_i - r_c - (\rho_i + \xi)\delta G(\Upsilon))\, q_i \,|\, \Upsilon\right]$, with the following retail quantity:

$$\check{q}_i(w_i, \rho_i) = \frac{1}{2}\Big(u - w_i - r_c - \gamma\,\mathbb{E}\left[q_j \,|\, \Upsilon\right] - (\rho_i + \xi)\delta G(\Upsilon)\Big).$$

The platform maximizes its expected revenue from retailer i conditional on Υ, i.e., $\mathbb{E}\,[\check{q}_i(w_i,\rho_i)\rho_i\delta G(\Upsilon)\,|\,\Upsilon]$, by setting the following brokerage fee:

$$\check{\rho}_i(w_i)=\frac{u-w_i-r_c-\delta\xi G(\Upsilon)-\gamma\,\mathbb{E}\,[q_j\,|\,\Upsilon]}{2\delta G(\Upsilon)}.$$

However, the manufacturer i does not observe Υ and thus maximizes his expected profit based on the public prior information, i.e., $\mathbb{E}\left[\check{q}_i(w_i,\check{\rho}_i(w_i))w_i-\frac{c}{2}[\check{q}_i(w_i,\check{\rho}_i(w_i))]^2\right]$, using the following wholesale price:

$$w_i^{\mathtt{P}}=w_i^{\mathtt{N}}=\frac{(c+4)\big(u-r_c-\theta\delta\xi-\gamma\,\mathbb{E}\,[q_j]\big)}{c+8}.$$

Then supply chain i's equilibrium retail quantity $q_i^{\mathtt{P}}(q_j):=\check{q}_i(w_i^{\mathtt{P}},\check{\rho}_i(w_i^{\mathtt{P}}))$ under partial information sharing is given as follows:

$$q_i^{\mathtt{P}}(q_j)=\frac{u-r_c}{c+8}+\frac{(c+4)\gamma}{4(c+8)}\,\mathbb{E}\,[q_j]-\frac{\gamma}{4}\,\mathbb{E}\,[q_j\,|\,\Upsilon]+\frac{(c+4)\theta-(c+8)G(\Upsilon)}{4(c+8)}\delta\xi. \tag{12}$$

Full Information Sharing. When the platform's information arrangement for the supply chain i is full information sharing (i.e., $\mathtt{Y}_i=\mathtt{F}$), both retailer i and manufacturer i observe the signal Υ. In this case, retailer i's order quantity and the platform's brokerage fee are $\check{q}_i(\cdot)$ and $\check{\rho}_i(\cdot)$, respectively. Furthermore, manufacturer i maximizes his expected profit conditional on Υ, i.e., $\mathbb{E}\left[\check{q}_i(w_i,\check{\rho}_i(w_i))w_i-\frac{c}{2}[\check{q}_i(w_i,\check{\rho}_i(w_i))]^2\,|\,\Upsilon\right]$, using the following wholesale price:

$$w_i^{\mathtt{F}}=\frac{(c+4)\big(u-r_c-G(\Upsilon)\delta\xi-\gamma\,\mathbb{E}\,[q_j\,|\,\Upsilon]\big)}{c+8}.$$

Consequently, supply chain i's equilibrium retail quantity $q_i^{\mathtt{F}}(q_j):=\check{q}_i(w_i^{\mathtt{F}},\check{\rho}_i(w_i^{\mathtt{F}}))$ under full information sharing is given as follows:

$$q_i^{\mathtt{F}}(q_j)=\frac{u-r_c}{c+8}-\frac{G(\Upsilon)\delta\xi}{c+8}-\frac{\gamma\,\mathbb{E}\,[q_j\,|\,\Upsilon]}{c+8}. \tag{13}$$

In summary, equations (11)–(13) characterize a focal supply chain i's equilibrium retail quantities $q_i^{\mathtt{Y}_i}(q_j)$ under the platform's possible information arrangements $\mathtt{Y}_i\in\{\mathtt{N},\mathtt{P},\mathtt{F}\}$. Given the conjecture q_i on supply chain i's retail quantity, we can follow the same steps to obtain rival supply chain j's retail quantity $q_j^{\mathtt{Y}_j}(q_i)$ for $\mathtt{Y}_j\in\{\mathtt{N},\mathtt{P},\mathtt{F}\}$. Using the expressions for $q_i^{\mathtt{Y}_i}(q_j)$ and $q_j^{\mathtt{Y}_j}(q_i)$, we are now ready to derive the Bayesian Nash equilibrium $(\hat{q}_i^{\mathtt{Y}_i,\mathtt{Y}_j},\hat{q}_j^{\mathtt{Y}_j,\mathtt{Y}_i})$ of competing supply chains' retail quantities. In particular, we have the following result:

Lemma 1. *Given the platform's possible information arrangements,* $\mathtt{Y}_i\in\{\mathtt{N},\mathtt{P},\mathtt{F}\}$ *and* $\mathtt{Y}_j\in\{\mathtt{N},\mathtt{P},\mathtt{F}\}$*, for competing supply chains, the Bayesian Nash equilibrium of their retail quantities are as follows:*

$$\hat{q}_i^{\mathtt{Y}_i,\mathtt{Y}_j}=\frac{u-r_c}{c+\gamma+8}+\varphi_i^{\mathtt{Y}_i,\mathtt{Y}_j}\theta+\phi_i^{\mathtt{Y}_i,\mathtt{Y}_j}G(\Upsilon),$$

$$\hat{q}_j^{\mathtt{Y}_j,\mathtt{Y}_i}=\frac{u-r_c}{c+\gamma+8}+\varphi_j^{\mathtt{Y}_j,\mathtt{Y}_i}\theta+\phi_j^{\mathtt{Y}_j,\mathtt{Y}_i}G(\Upsilon),$$

where the coefficients $(\varphi_i^{\mathtt{Y}_i,\mathtt{Y}_j}, \phi_i^{\mathtt{Y}_i,\mathtt{Y}_j}, \varphi_j^{\mathtt{Y}_j,\mathtt{Y}_i}, \phi_j^{\mathtt{Y}_j,\mathtt{Y}_i})$ *are given by:*

	$\varphi_i^{\mathtt{Y}_i,\mathtt{Y}_j}$	$\phi_i^{\mathtt{Y}_i,\mathtt{Y}_j}$	$\varphi_j^{\mathtt{Y}_j,\mathtt{Y}_i}$	$\phi_j^{\mathtt{Y}_j,\mathtt{Y}_i}$
$\mathtt{Y}_i = \mathtt{N}, \mathtt{Y}_j = \mathtt{N}$	$-\frac{\xi\delta}{c+\gamma+8}$	0	$-\frac{\xi\delta}{c+\gamma+8}$	0
$\mathtt{Y}_i = \mathtt{P}, \mathtt{Y}_j = \mathtt{N}$	$\frac{\xi\delta(c+\gamma+4)}{4(c+\gamma+8)}$	$-\frac{\xi\delta}{4}$	$-\frac{\xi\delta}{c+\gamma+8}$	0
$\mathtt{Y}_i = \mathtt{N}, \mathtt{Y}_j = \mathtt{P}$	$-\frac{\xi\delta}{c+\gamma+8}$	0	$\frac{\xi\delta(c+\gamma+4)}{4(c+\gamma+8)}$	$-\frac{\xi\delta}{4}$
$\mathtt{Y}_i = \mathtt{F}, \mathtt{Y}_j = \mathtt{N}$	$\frac{\gamma\xi\delta}{(c+8)(c+\gamma+8)}$	$-\frac{\xi\delta}{c+8}$	$-\frac{\xi\delta}{c+\gamma+8}$	0
$\mathtt{Y}_i = \mathtt{N}, \mathtt{Y}_j = \mathtt{F}$	$-\frac{\xi\delta}{c+\gamma+8}$	0	$\frac{\gamma\xi\delta}{(c+8)(c+\gamma+8)}$	$-\frac{\xi\delta}{c+8}$
$\mathtt{Y}_i = \mathtt{F}, \mathtt{Y}_j = \mathtt{F}$	0	$-\frac{\xi\delta}{c+\gamma+8}$	0	$-\frac{\xi\delta}{c+\gamma+8}$
$\mathtt{Y}_i = \mathtt{F}, \mathtt{Y}_j = \mathtt{P}$	$-\frac{(c+4)\gamma\xi\delta}{(c+\gamma+8)(32-\gamma^2+4c)}$	$-\frac{(4-\gamma)\xi\delta}{32-\gamma^2+4c}$	$\frac{(c+4)(c+8)\xi\delta}{(c+\gamma+8)(32-\gamma^2+4c)}$	$-\frac{(c-\gamma+8)\xi\delta}{32-\gamma^2+4c}$
$\mathtt{Y}_i = \mathtt{P}, \mathtt{Y}_j = \mathtt{F}$	$\frac{(c+4)(c+8)\xi\delta}{(c+\gamma+8)(32-\gamma^2+4c)}$	$-\frac{(c-\gamma+8)\xi\delta}{32-\gamma^2+4c}$	$-\frac{(c+4)\gamma\xi\delta}{(c+\gamma+8)(32-\gamma^2+4c)}$	$-\frac{(4-\gamma)\xi\delta}{32-\gamma^2+4c}$
$\mathtt{Y}_i = \mathtt{P}, \mathtt{Y}_j = \mathtt{P}$	$\frac{(c+4)\xi\delta}{(\gamma+4)(c+\gamma+8)}$	$-\frac{\xi\delta}{\gamma+4}$	$\frac{(c+4)\xi\delta}{(\gamma+4)(c+\gamma+8)}$	$-\frac{\xi\delta}{\gamma+4}$

Lemma 1 shows that the equilibrium retail quantities for competing supply chains are linear combinations of the prior and posterior probabilities, θ and $G(\Upsilon)$, respectively. This result also allows us to make the following observations. First, we can use the variances $\mathrm{Var}\,[\hat{q}_i^{\mathtt{Y}_i,\mathtt{Y}_j}]$ and $\mathrm{Var}\,[\hat{q}_j^{\mathtt{Y}_j,\mathtt{Y}_i}]$ to assess the responsiveness of the equilibrium retail quantities of competing supply chains to carrier freight rejection. Specifically, by Lemma 1, we find that for any $\mathtt{Y}_j \in \{\mathtt{N},\mathtt{P},\mathtt{F}\}$ the following inequalities hold:

$$\begin{aligned} &\mathrm{Var}\,[\hat{q}_i^{\mathtt{P},\mathtt{Y}_j}] \geq \mathrm{Var}\,[\hat{q}_i^{\mathtt{F},\mathtt{Y}_j}] \geq \mathrm{Var}\,[\hat{q}_i^{\mathtt{N},\mathtt{Y}_j}], \\ &\mathrm{Var}\,[\hat{q}_j^{\mathtt{Y}_j,\mathtt{N}}] \geq \mathrm{Var}\,[\hat{q}_j^{\mathtt{Y}_j,\mathtt{F}}] \geq \mathrm{Var}\,[\hat{q}_j^{\mathtt{Y}_j,\mathtt{P}}]. \end{aligned} \tag{14}$$

The first inequality in (14) means that both of the platform's information sharing strategies enhance the responsiveness of a focal supply chain i's equilibrium retail quantity to carrier freight rejection relative to no information sharing. Furthermore, partial information sharing enhances this responsiveness more. The second inequality means that both of the platform's information sharing strategies reduce the responsiveness of the rival supply chain j's equilibrium retail quantity. Moreover, partial information sharing results in a greater reduction of responsiveness.

Second, using Lemma 1, we can derive expressions for the ex-ante payoffs of every player under the platform's different information arrangements for the competing supply chains. To that end, we define $\boldsymbol{\phi}_i^{\mathtt{Y}_i,\mathtt{Y}_j} := (\varphi_i^{\mathtt{Y}_i,\mathtt{Y}_j}, \phi_i^{\mathtt{Y}_i,\mathtt{Y}_j})$ and $\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{Y}_i} := (\varphi_j^{\mathtt{Y}_j,\mathtt{Y}_i}, \phi_j^{\mathtt{Y}_j,\mathtt{Y}_i})$. Given rival supply chain j's equilibrium retail quantity $\hat{q}_j^{\mathtt{Y}_j,\mathtt{Y}_i}$, we can write the customer demand for retailer i as $u_i(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{Y}_i}) - q_i$, where

$$u_i(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{Y}_i}) = u - \gamma\, q_j^{\mathtt{Y}_j,\mathtt{Y}_i} = \frac{(c+8)u + \gamma r_c}{c+\gamma+8} - \gamma\,(\varphi_j^{\mathtt{Y}_j,\mathtt{Y}_i}\theta + \phi_j^{\mathtt{Y}_j,\mathtt{Y}_i} G(\Upsilon))$$

is a constant reflecting the competition effect. Using the expression for $u_i(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{Y}_i})$, we follow the analysis of single supply chain to derive the ex-ante payoffs for retailer i and manufacturer i, denoted by $\Pi^{\mathtt{Y}_i}_{R_i}(\boldsymbol{\phi}^{\mathtt{Y}_j,\mathtt{Y}_i}_j)$ and $\Pi^{\mathtt{Y}_i}_{M_i}(\boldsymbol{\phi}^{\mathtt{Y}_j,\mathtt{Y}_i}_j)$, respectively. We can also derive the platform's ex-ante payoff from retailer i, denoted by $\Pi^{\mathtt{Y}_i}_{P_i}(\boldsymbol{\phi}^{\mathtt{Y}_j,\mathtt{Y}_i}_j)$. Similarly, we can determine the ex-ante payoffs for retailer j and manufacturer j, denoted by $\Pi^{\mathtt{Y}_j}_{R_j}(\boldsymbol{\phi}^{\mathtt{Y}_i,\mathtt{Y}_j}_i)$ and $\Pi^{\mathtt{Y}_j}_{M_j}(\boldsymbol{\phi}^{\mathtt{Y}_i,\mathtt{Y}_j}_i)$, together with the platform's ex-ante payoff from retailer j, denoted by $\Pi^{\mathtt{Y}_j}_{P_j}(\boldsymbol{\phi}^{\mathtt{Y}_i,\mathtt{Y}_j}_i)$. A summary of every player's ex-ante payoffs under the platform's different information arrangement for competing supply chains is provided in Lemma 4 in the Appendix.

5.2. Effect of Information Sharing on Competing Supply Chains

Given the rival supply chain j's information arrangement $\mathtt{Y}_j \in \{\mathtt{N},\mathtt{P},\mathtt{F}\}$, relative to the benchmark of no information sharing, the platform's information sharing strategy with focal supply chain i affects the ex-ante payoffs of retailer i and manufacturer i as follows:

$$\Pi^{\mathtt{Y}_i}_{R_i}(\boldsymbol{\phi}^{\mathtt{Y}_j,\mathtt{Y}_i}_j) - \Pi^{\mathtt{N}}_{R_i}(\boldsymbol{\phi}^{\mathtt{Y}_j,\mathtt{N}}_j), \quad \Pi^{\mathtt{Y}_i}_{M_i}(\boldsymbol{\phi}^{\mathtt{Y}_j,\mathtt{Y}_i}_j) - \Pi^{\mathtt{N}}_{M_i}(\boldsymbol{\phi}^{\mathtt{Y}_j,\mathtt{N}}_j), \quad \mathtt{Y}_i \in \{\mathtt{P},\mathtt{F}\}.$$

Simultaneously, the platform's information sharing strategy to the focal supply chain i also affects its own ex-ante payoffs as follows:

$$\left[\Pi^{\mathtt{Y}_i}_{P_i}(\boldsymbol{\phi}^{\mathtt{Y}_j,\mathtt{Y}_i}_j) + \Pi^{\mathtt{Y}_j}_{P_j}(\boldsymbol{\phi}^{\mathtt{Y}_i,\mathtt{Y}_j}_i)\right] - \left[\Pi^{\mathtt{N}}_{P_i}(\boldsymbol{\phi}^{\mathtt{Y}_j,\mathtt{N}}_j) + \Pi^{\mathtt{Y}_j}_{P_j}(\boldsymbol{\phi}^{\mathtt{N},\mathtt{Y}_j}_i)\right], \quad \mathtt{Y}_i \in \{\mathtt{P},\mathtt{F}\}.$$

Lemma 2. *Relative to the benchmark of no information sharing,*

(a) Partial information sharing always benefits retailer i and the platform, but hurts manufacturer i regardless of rival supply chain j's information arrangement (i.e., for all $\mathtt{Y}_j \in \{\mathtt{N},\mathtt{P},\mathtt{F}\}$).

(b) Full information sharing always benefits retailer i and manufacturer i, but hurts the platform if rival supply chain j's information arrangement is partial information sharing (i.e., $\mathtt{Y}_j = \mathtt{P}$) when $c \geq \frac{\gamma^3+4\gamma^2-80\gamma+64}{8\gamma}$.

Part (a) of Lemma 2 shows that the retailers and the platform are always incentivized to adopt partial information sharing. This is because they obtain payoff surplus by enhancing the responsiveness of their equilibrium decisions to carrier freight rejection. Part (b) of Lemma 2 shows that full information sharing can hurt the platform when rival supply chain j's information arrangement is partial information sharing if the manufacturer's production diseconomy is sufficiently large (i.e., $c \geq \frac{\gamma^3+4\gamma^2-80\gamma+64}{8\gamma}$). This is because the DME reduces the platform's revenue from retailer j (i.e., $\Pi^{\mathtt{P}}_{P_j}(\boldsymbol{\phi}^{\mathtt{FP}}_i) - \Pi^{\mathtt{P}}_{P_j}(\boldsymbol{\phi}^{\mathtt{NP}}_i) < 0$). Notably, this result differs from the previous result in single supply chain (see Proposition 1(b)). An important implication of Lemma 2 is that no information sharing is dominated by partial information sharing for each of the competing supply chains. Hence, it is safe to ignore the benchmark strategy in the following analysis, as the platform's equilibrium information strategy for each competing supply chains is always a choice between partial and full information sharing.

Next, we explore the effect of the platform's full information sharing, relative to partial information sharing, on the players in a focal supply chain i. Given rival supply chain j's information arrangement $\mathtt{Y}_j \in \{\mathtt{P}, \mathtt{F}\}$, we assess the effect of full information sharing on the ex-ante payoffs of retailer i and manufacturer i as follows:

$$\Pi^{\mathtt{F}}_{R_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{F}}) - \Pi^{\mathtt{P}}_{R_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}}) = \underbrace{\left[\Pi^{\mathtt{F}}_{R_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}}) - \Pi^{\mathtt{P}}_{R_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}})\right]}_{\text{Direct effect on retailer } i} + \underbrace{\left[\Pi^{\mathtt{F}}_{R_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{F}}) - \Pi^{\mathtt{F}}_{R_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}})\right]}_{\text{Competitive effect on retailer } i},$$

$$\Pi^{\mathtt{F}}_{M_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{F}}) - \Pi^{\mathtt{P}}_{M_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}}) = \underbrace{\left[\Pi^{\mathtt{F}}_{M_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}}) - \Pi^{\mathtt{P}}_{M_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}})\right]}_{\text{Direct effect on manufacturer } i} + \underbrace{\left[\Pi^{\mathtt{F}}_{M_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{F}}) - \Pi^{\mathtt{F}}_{M_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}})\right]}_{\text{Competitive effect on manufacturer } i}.$$

Following Ha et al. (2011), we decompose the effect of full information sharing on retailer i, i.e., $\Pi^{\mathtt{F}}_{R_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{F}}) - \Pi^{\mathtt{P}}_{R_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}})$, into two components. The first component is the direct effect ignoring rival supply chain j's reaction, i.e., $\Pi^{\mathtt{F}}_{R_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}}) - \Pi^{\mathtt{P}}_{R_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}})$, while the second component is the competitive effect, i.e., $\Pi^{\mathtt{F}}_{R_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{F}}) - \Pi^{\mathtt{F}}_{R_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}})$. The effect of full information sharing on manufacturer i can be decomposed similarly.

Simultaneously, the platform's full information sharing to the focal supply chain i also affects its own ex-ante payoffs as follows:

$$\begin{aligned}
&\left[\Pi^{\mathtt{F}}_{P_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{F}}) + \Pi^{\mathtt{Y}_j}_{P_j}(\boldsymbol{\phi}_i^{\mathtt{F},\mathtt{Y}_j})\right] - \left[\Pi^{\mathtt{P}}_{P_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}}) + \Pi^{\mathtt{Y}_j}_{P_j}(\boldsymbol{\phi}_i^{\mathtt{P},\mathtt{Y}_j})\right] \\
= &\underbrace{\left[\Pi^{\mathtt{F}}_{P_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}}) - \Pi^{\mathtt{P}}_{P_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}})\right]}_{\text{Direct effect on the platform}} + \underbrace{\left[\Pi^{\mathtt{F}}_{P_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{F}}) - \Pi^{\mathtt{F}}_{P_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}})\right]}_{\text{Competitive effect on the platform}} + \underbrace{\left[\Pi^{\mathtt{Y}_j}_{P_j}(\boldsymbol{\phi}_i^{\mathtt{F},\mathtt{Y}_j}) - \Pi^{\mathtt{Y}_j}_{P_j}(\boldsymbol{\phi}_i^{\mathtt{P},\mathtt{Y}_j})\right]}_{\text{Spillover effect on the platform}},
\end{aligned}$$

where the terms $\Pi^{\mathtt{F}}_{P_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}}) - \Pi^{\mathtt{P}}_{P_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}})$, $\Pi^{\mathtt{F}}_{P_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{F}}) - \Pi^{\mathtt{F}}_{P_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}})$, and $\Pi^{\mathtt{Y}_j}_{P_j}(\boldsymbol{\phi}_i^{\mathtt{F},\mathtt{Y}_j}) - \Pi^{\mathtt{Y}_j}_{P_j}(\boldsymbol{\phi}_i^{\mathtt{P},\mathtt{Y}_j})$ represent the direct, competitive, and spillover effects of full information sharing on the platform, respectively.

Lemma 3. *Relative to partial information sharing,*

(a) Full information sharing has direct and competitive effects that hurt retailer i, ultimately resulting in net harm to retailer i.

(b) Full information sharing has a direct effect that benefits manufacturer i and a competitive effect that hurts him, ultimately resulting in a net benefit to manufacturer i.

(c) Full information sharing has direct and competitive effects that hurt the platform and a spillover effect that benefits it, ultimately resulting in net harm to the platform.

The direct effect of full information sharing on every player is similar to the previous result given in Proposition 1(c). Next, we explain the the competitive and spillover effects of full information sharing. Since full information sharing in a focal supply chain i enables retailer i, manufacturer i, and the platform to better respond to carrier freight rejection, these players' ex-ante payoffs increase as the supply chain's equilibrium demand (i.e., equilibrium retail quantity) becomes more variable. As shown in (14), full information sharing in the focal supply chain i makes its own demand less variable, which leads to the negative competitive effect on retailer i, manufacturer i, and the platform. Meanwhile, full information sharing in a focal supply chain i also makes rival supply chain j's equilibrium retail demand more variable, which results in the positive spillover effect on the platform. It is worth mentioning that Lemma 3 extends the analysis of the effect of information sharing in the literature (e.g., Ha et al. (2011, 2017)) by decomposing the effect of the platform's information sharing strategy on itself into direct, competitive, and spillover effects, and shows that the former two negative effects outweighs the latter positive effect.

5.3. Platform's Strategic Information Decisions

Lemma 3 implies that full information sharing can be induced in supply chain i through manufacturer i offering a side payment to retailer i and the platform, provided that manufacturer i generates a nonnegative surplus (considering the side payment) from full information sharing, which is given by:

$$\begin{aligned}\left[\Pi^{\mathtt{F}}_{M_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{F}}) - \Pi^{\mathtt{P}}_{M_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}})\right] + &\underbrace{\left[\Pi^{\mathtt{F}}_{R_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{F}}) - \Pi^{\mathtt{P}}_{R_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}})\right]}_{\text{Side payment to retailer } i} \\ &+ \underbrace{\left[\Pi^{\mathtt{F}}_{P_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{F}}) + \Pi^{\mathtt{Y}_j}_{P_j}(\boldsymbol{\phi}_i^{\mathtt{F},\mathtt{Y}_j})\right] - \left[\Pi^{\mathtt{P}}_{P_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{P}}) + \Pi^{\mathtt{Y}_j}_{P_j}(\boldsymbol{\phi}_i^{\mathtt{P},\mathtt{Y}_j})\right]}_{\text{Side payment to the platform}}.\end{aligned}$$

Otherwise, partial information sharing will be adopted. In other words, given rival supply chain j's information arrangement $\mathtt{Y}_j \in \{\mathtt{P},\mathtt{F}\}$, the platform's information sharing strategy in focal supply chain i stems from manufacturer i's choice $\mathtt{Y}_i \in \{\mathtt{P},\mathtt{F}\}$ depending on the sign of his gross payoff. Likewise, we can obtain the platform's information sharing strategy for rival supply chain j. Moreover, in the context of supply chain competition, the two manufacturers' choices of information sharing strategies can be treated as a Nash game with simultaneous moves from their own action spaces $\mathtt{Y}_i \times \mathtt{Y}_j \in \{\mathtt{P},\mathtt{F}\} \times \{\mathtt{P},\mathtt{F}\}$. By defining the following terms,

$$v^{\mathtt{FF}} := \frac{4(c-\gamma+8)^2\delta^2\xi^2}{(4(c+8)-\gamma^2)^2}, \quad v^{\mathtt{FP}} := \frac{2(c-\gamma+8)^2\delta^2\xi^2}{(4(c+8)-\gamma^2)^2} + \frac{2\delta^2\xi^2}{(\gamma+4)^2}, \quad v^{\mathtt{PP}} := \frac{4\delta^2\xi^2}{(\gamma+4)^2},$$

we can summarize the platform's equilibrium information sharing strategies as follows.

Proposition 4. *For competing supply chains, we have the following:*

(a) There exist unique pair of constants $(\hat{c}^{\mathtt{PP}}, \hat{c}^{\mathtt{FF}})$ *with* $\hat{c}^{\mathtt{PP}} < \hat{c}^{\mathtt{FF}}$ *such that:*

- *If* $c \geq \hat{c}^{\mathtt{FF}}$*, then* $(\mathtt{F},\mathtt{F})$ *is the unique equilibrium strategy.*

- *If* $\hat{c}^{\mathtt{PP}} \le c < \hat{c}^{\mathtt{FF}}$*, then* $(\mathtt{P},\mathtt{F})$ *and* $(\mathtt{F},\mathtt{P})$ *are two possible equilibria strategies.*
- *If* $c < \hat{c}^{\mathtt{PP}}$*, then* $(\mathtt{P},\mathtt{P})$ *is the unique equilibrium strategy.*

(b) Accounting for possible side payments, the platform's equilibrium gross payoff is given by:

$$\frac{4(u - r_c - \xi\delta\theta)^2}{(c + \gamma + 8)^2} + \tilde{v}\eta, \tag{15}$$

where the constant $\tilde{v}$ *is given as follows: If* $c \ge \hat{c}^{\mathtt{FF}}$*, then* $\tilde{v} = v^{\mathtt{FF}}$*; if* $\hat{c}^{\mathtt{PP}} \le c < \hat{c}^{\mathtt{FF}}$*, then* $\tilde{v} = v^{\mathtt{FP}}$*; and if* $c < \hat{c}^{\mathtt{PP}}$*, then* $\tilde{v} = v^{\mathtt{PP}}$*.*

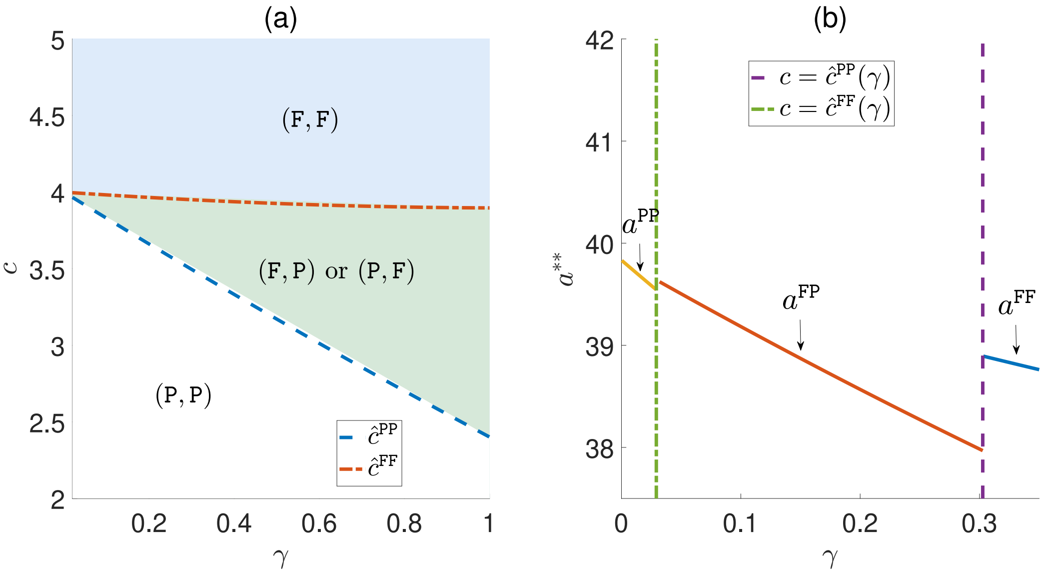
(c) The thresholds $(\hat{c}^{\mathtt{PP}}, \hat{c}^{\mathtt{FF}})$ *given in part (a) are both decreasing in* γ*, and their difference* $\hat{c}^{\mathtt{FF}} - \hat{c}^{\mathtt{PP}}$ *is increasing in* γ*.*

Part (a) of Proposition 4 characterizes the platform's equilibrium information sharing formats (see Figure 3(a)) based on the relationship between c and two thresholds $(\hat{c}^{\mathtt{PP}}, \hat{c}^{\mathtt{FF}})$. First, if c is sufficiently large such that $c \ge \hat{c}^{\mathtt{FF}}$, the manufacturer in each supply chain is incentivized to induce full information sharing, regardless of the rival supply chain's information arrangement. Consequently, the platform implements a symmetric full information sharing strategy for the competing supply chains, i.e., $(\mathtt{F},\mathtt{F})$ is the unique equilibrium. Second, if c is sufficiently small such that $c < \hat{c}^{\mathtt{PP}}$, the manufacturer in each supply chain is not incentivized to induce full information sharing, regardless of the rival supply chain's information arrangement. Accordingly, the platform implements a symmetric partial information sharing strategy, i.e., $(\mathtt{P},\mathtt{P})$ is the unique equilibrium. Third, if c is moderate and satisfies $\hat{c}^{\mathtt{PP}} \le c < \hat{c}^{\mathtt{FF}}$, the manufacturer in a focal supply chain induces full information sharing only when the rival supply chain adopts partial information sharing. In this case, one supply chain adopts full information sharing and the other one adopts partial information sharing, so that $(\mathtt{P},\mathtt{F})$ and $(\mathtt{F},\mathtt{P})$ are the two possible equilibria. Hence, the platform uses an asymmetric mixed information sharing strategy.

Part (b) of Proposition 4 is a summary of the platform's gross payoffs under each equilibrium information sharing format. In (15), the terms $4(u - r_c - \xi\delta\theta)^2/(c + \gamma + 8)^2$ and $\tilde{v}\eta$ stem from the public prior information and the platform's private information about freight market conditions, respectively. Moreover, the constant $\tilde{v}$, which represents the marginal value of the platform's information sharing, varies as the platform's equilibrium information sharing format changes. It is easy to verify that $v^{\mathtt{FF}} \ge v^{\mathtt{FP}} \ge v^{\mathtt{PP}}$, implying that the marginal value of the platform's information sharing decreases as the equilibrium information sharing format switches from symmetric full information sharing to symmetric partial information sharing.

Part (c) of Proposition 4 also reveals the impact of supply chain competition on the equilibrium information sharing formats (see Figure 3(a)). As the competition intensity γ increases, symmetric partial information sharing is less likely to be chosen (since $\hat{c}^{\mathtt{PP}}$ is decreasing in γ), while symmetric full information sharing is more likely to be adopted (since $\hat{c}^{\mathtt{FF}}$ is decreasing in γ). In addition, asymmetric mixed information sharing is more likely to be adopted as well (since $\hat{c}^{\mathtt{FF}} - \hat{c}^{\mathtt{PP}}$ is increasing in γ).

Figure 3 **The platform's strategic information decisions for competing supply chains when the cost function $w(a)$ has a linear form. Figure (a) depicts the boundary conditions for equilibrium information sharing strategies in the parameter space (c, γ). Figure (b) visualizes the comparative statics of the platform's optimal information accuracy decision and payoff for different values of γ.**



Based on the above results, we are ready to examine the platform's problem of maximizing its net payoff (i.e., the platform's equilibrium gross payoff minus the information cost) by optimizing the accuracy a of its private information. In particular, the platform solves the following problem:

$$\max_{a\geq 4}\left\{\frac{4(u-r_c-\xi\delta\theta)^2}{\delta(c+\gamma+8)^2}+\tilde{v}\eta(a)-w(a)\right\},$$

where $\eta(a)$ is given by (9). Recall that from Proposition 4, the parameter $\tilde{v}$ varies as the platform's equilibrium information sharing formats change. Thus, for all the equilibrium information sharing formats, we define the following unique solutions: $a^{\mathtt{FF}} := \arg\max_{a\geq 4}\{v^{\mathtt{FF}}\eta(a) - w(a)\}$, $a^{\mathtt{FP}} := \arg\max_{a\geq 4}\{v^{\mathtt{FP}}\eta(a) - w(a)\}$, and $a^{\mathtt{PP}} := \arg\max_{a\geq 4}\{v^{\mathtt{PP}}\eta(a) - w(a)\}$.

Proposition 5. *For competing supply chains, the platform's optimal information acquisition decision a^{**} is given by:*

$$a^{**} = \begin{cases} a^{\mathtt{FF}}, & \textit{if } c \geq \hat{c}^{\mathtt{FF}}, \\ a^{\mathtt{FP}}, & \textit{if } \hat{c}^{\mathtt{PP}} \leq c < \hat{c}^{\mathtt{FF}}, \\ a^{\mathtt{PP}}, & \textit{if } c < \hat{c}^{\mathtt{PP}}, \end{cases}$$

with $a^{\mathsf{FF}} \geq a^{\mathsf{FP}} \geq a^{\mathsf{PP}}$*. Moreover, the following hold:*

(a) a^{FF}*,* a^{FP} *and* a^{PP} *are all increasing in* $[0, \frac{1}{2}]$ *and decreasing in* $[\frac{1}{2}, 1]$*.*

(b) a^{FF}*,* a^{FP} *and* a^{PP} *are increasing in* δ*.*

(c) a^{FF}*,* a^{FP} *and* a^{PP} *are decreasing in* γ*.*

(d) When $w(a)$ *has a linear form* $w(a) = ka$ *with* $k > 0$*, we obtain the following closed form expressions:*

$$a^{\mathsf{FF}} = 4 + \left(\sqrt{\frac{v^{\mathsf{FF}}}{k}} - \frac{1}{(1-\theta)\theta}\right)^{+}, \quad a^{\mathsf{FP}} = 4 + \left(\sqrt{\frac{v^{\mathsf{FP}}}{k}} - \frac{1}{(1-\theta)\theta}\right)^{+}, \quad a^{\mathsf{PP}} = 4 + \left(\sqrt{\frac{v^{\mathsf{PP}}}{k}} - \frac{1}{(1-\theta)\theta}\right)^{+}.$$

Proposition 5 shows that the platform's optimal information accuracy decision for competing supply chains has a piecewise form depending on c. That is, a^{**} is shaped by the three terms a^{FF}, a^{FP} and a^{PP}, which are the optimal information accuracy under symmetric full information sharing, asymmetric mixed information sharing, and symmetric partial information sharing, respectively. Furthermore, due to the fact that $v^{\mathsf{PP}} \leq v^{\mathsf{FP}} \leq v^{\mathsf{FF}}$, we also obtain the inequality $a^{\mathsf{PP}} \leq a^{\mathsf{FP}} \leq a^{\mathsf{FF}}$, which means that the platform would improve the accuracy of its private information as the platform switches from symmetric full information sharing to symmetric partial information sharing.

Parts (a) and (b) of Proposition 5 show the comparative statics of the terms $(a^{\mathsf{FF}}, a^{\mathsf{FP}}, a^{\mathsf{PP}})$ with respect to θ and δ. In particular, the monotonic behavior of these terms with respect to δ implies that a^{**} is increasing in δ. Therefore, the previous finding (see Proposition 2) on the impact of changing the probability δ of carrier freight rejection on the platform's optimal information accuracy decision continues to hold in the competing supply chains. Part (c) of Proposition 5 reveals the impact of supply chain competition on the platform's optimal information accuracy decision. As the competition intensity γ increases, the marginal values v^{FF}, v^{FP}, and v^{PP} of the platform's information sharing strategies decrease, compelling the platform reduce the information accuracy under every equilibrium information sharing format (i.e., the terms $a^{\mathsf{FF}}, a^{\mathsf{FP}}$, and a^{PP} are all decreasing in γ). Interestingly, the monotonic behavior of a^{FF}, a^{FP}, and a^{PP} with respect to γ does not necessarily mean that the platform's optimal information accuracy decision a^{**} is decreasing in γ. In particular, as illustrated by Figure 3(b), even though the platform's information accuracy decision is decreasing in γ under every equilibrium format, there are jumps in the information accuracy as the platform switches the equilibrium information sharing format; for example, a^{**} jumps from a^{FP} to a^{FF} as the platform switches from asymmetric mixed information sharing to symmetric full information sharing. In summary, as supply chain competition intensifies, the platform has disruptive improvements in its information accuracy as it switches equilibrium information sharing formats; however, under every equilibrium information sharing format, the platform's information accuracy decision decreases as the competition intensity increases.

6. Concluding Remarks

Motivated by real-world supply chain logistics practice, this paper studies how digital freight platforms share information to firms in supply chains to improve their responsiveness to carrier freight rejection. We characterize a digital freight platform's equilibrium information sharing strategy (either partial or full information sharing) for a single supply chain consisting of a retailer and a manufacturer. We also explore the platform's optimal information accuracy decision under the equilibrium information sharing strategy. Our analysis reveals that the probability of carrier freight rejection is a positive factor that encourages the platform to improve its information accuracy. Interestingly, we also find the retailer's net payoff under the platform's information accuracy decision is first decreasing and then increasing in the probability of carrier freight rejection. This suggests that a higher probability of carrier freight rejection could benefit the shipper under the platform's information sharing strategy.

We then extend our analysis by considering a digital freight platform's information sharing to competing supply chains. We find that the platform has three equilibrium information sharing formats: (a) symmetric full information sharing, (b) asymmetric mixed information sharing, and (c) symmetric partial information sharing. As the manufacturer's production diseconomy increases, the platform gradually switches the equilibrium information sharing formats from (a) to (c). Moreover, the impact of the probability of carrier freight rejection on the platform's optimal information accuracy continues to hold in the case of supply chain competition. Our research also explores the impact of supply chain competition on the platform. We find that supply chain competition benefits the platform, leading the platform to transition towards adopting symmetric information sharing at equilibrium for competing supply chains. However, once symmetric information sharing is fixed, supply chain competition hurts the platform, as it reduces the platform's marginal benefit from improving responsiveness to carrier freight rejection.

This paper can be extended in different directions. First, given the benefits of accurate predictive information on freight market conditions, supply chains and digital freight platforms could collaborate to improve the accuracy of the predictive information together. An interesting extension of this work is to explore equilibrium decision making under different collaboration schemes and discuss the allocation of collaborative values among different players. Second, for analytical convenience, we only considered symmetric supply chains with identical cost parameters in this paper. An interesting extension is to consider asymmetric supply chains with different cost parameters.

References

Acocella, Angela, Chris Caplice, Yossi Sheffi. 2022. The end of "set it and forget it" pricing? opportunities for market-based freight contracts. *arXiv preprint arXiv:2202.02367* .

Aemireddy, Nishitha Reddy, Xiyang Yuan. 2019. Root cause analysis and impact of unplanned procurement on truckload transportation costs, m. eng in logistics thesis.

Boada-Collado, Pol, Sunil Chopra, Karen Smilowitz. 2020. Partial demand information and commitment in dynamic transportation procurement. *Transportation Science* **54**(3) 588–605.

Cao, Yufeng, Anton Kleywegt, He Wang. 2022. Dynamic pricing for two-sided marketplaces with offer expiration. *Available at SSRN 3700227* .

Caplice, Chris. 2007. Electronic markets for truckload transportation. *Production and Operations Management* **16**(4) 423–436.

Caplice, Chris. 2021. Reducing uncertainty in freight transportation procurement. *Journal of Supply Chain Management, Logistics and Procurement* **4**(2) 137–155.

Colombo, Luca, Gianluca Femminis. 2008. The social value of public information with costly information acquisition. *Economics Letters* **100**(2) 196–199.

Guo, Jiantao, Juliang Zhang, TCE Cheng, Shouting Zhao. 2022. Truthful double auction mechanisms for online freight platforms with transaction costs. *Transportation Research Part B: Methodological* **158** 164–186.

Ha, Albert Y, Huajiang Luo, Weixin Shang. 2022. Supplier encroachment, information sharing, and channel structure in online retail platforms. *Production and Operations Management* **31**(3) 1235–1251.

Ha, Albert Y, Quan Tian, Shilu Tong. 2017. Information sharing in competing supply chains with production cost reduction. *Manufacturing & Service Operations Management* **19**(2) 246–262.

Ha, Albert Y, Shilu Tong, Hongtao Zhang. 2011. Sharing demand information in competing supply chains with production diseconomies. *Management science* **57**(3) 566–581.

Han, Bing, Liyan Yang. 2013. Social networks, information acquisition, and asset prices. *Management Science* **59**(6) 1444–1457.

Inderfurth, Karl, Peter Kelle, Rainer Kleber. 2013. Dual sourcing using capacity reservation and spot market: Optimal procurement policy and heuristic parameter determination. *European Journal of Operational Research* **225**(2) 298–309. doi:https://doi.org/10.1016/j.ejor.2012.08.025. URL `https://www.sciencedirect.com/science/article/pii/S0377221712006625`.

Kurtuluş, Mümin, Sezer Ülkü, Beril L Toktay. 2012. The value of collaborative forecasting in supply chains. *Manufacturing & Service Operations Management* **14**(1) 82–98.

Lee, Hau L, Kut C So, Christopher S Tang. 2000. The value of information sharing in a two-level supply chain. *Management science* **46**(5) 626–643.

Li, Jianbin, Yuting Zheng, Bin Dai, Jiang Yu. 2020. Implications of matching and pricing strategies for multiple-delivery-points service in a freight o2o platform. *Transportation Research Part E: Logistics and Transportation Review* **136** 101871.

Li, Lode. 2002. Information sharing in a supply chain with horizontal competition. *Management science* **48**(9) 1196–1212.

Liu, Zekun, Dennis J Zhang, Fuqiang Zhang. 2021. Information sharing on retail platforms. *Manufacturing & Service Operations Management* **23**(3) 606–619.

Lu, Tao, Ying-Ju Chen, Jan C Fransoo, Chung-Yee Lee. 2020. Shipping to heterogeneous customers with competing carriers. *Manufacturing & Service Operations Management* **22**(4) 850–867.

Lu, Tao, Jan C Fransoo, Chung-Yee Lee. 2017. Carrier portfolio management for shipping seasonal products. *Operations Research* **65**(5) 1250–1266.

Miller, John, Yu Nie, Xiaobo Liu. 2020. Hyperpath truck routing in an online freight exchange platform. *Transportation Science* **54**(6) 1676–1696.

Min, Daiki, Yuncheol Kang. 2021. A learning-based approach for dynamic freight brokerages with transfer and territory-based assignment. *Computers & Industrial Engineering* **153** 107042.

Pyzyk, Katie. 2021. Tms integrations with digital freight brokers are gaining momentum. *https://www.supplychaindive.com/news/digital-broker-tms-integrations-api-supply-chain-transportation/599477/* .

Scott, Alex. 2015. The value of information sharing for truckload shippers. *Transportation Research Part E: Logistics and Transportation Review* **81** 203–214.

Scott, Alex, Chris Parker, Christopher W Craighead. 2017. Service refusals in supply chains: Drivers and deterrents of freight rejection. *Transportation Science* **51**(4) 1086–1101.

Shang, Weixin, Albert Y Ha, Shilu Tong. 2016. Information sharing in a supply chain with a common retailer. *Management Science* **62**(1) 245–263.

Shi, Ye, Layth C Alwan, Srinivasan Raghunathan, Yugang Yu, Xiaohang Yue. 2021. Mobile consumer scanning technology: A replacement for interorganizational information systems for demand information learning in supply chains? *Information Systems Research* **32**(4) 1431–1449.

Stenius, Olof, Johan Marklund, Sven Axsäter. 2018. Sustainable multi-echelon inventory control with shipment consolidation and volume dependent freight costs. *European Journal of Operational Research* **267**(3) 904–916.

Tsai, Mei-Ting, Jean-Daniel Saphores, Amelia Regan. 2011. Valuation of freight transportation contracts under uncertainty. *Transportation Research Part E: Logistics and Transportation Review* **47**(6) 920–932.

Tsunoda, Yushi, Yusuke Zennyo. 2021. Platform information transparency and effects on third-party suppliers and offline retailers. *Production and Operations Management* **30**(11) 4219–4235.

Zhou, Zenan, Xiang Wan. 2022. Does the sharing economy technology disrupt incumbents? exploring the influences of mobile digital freight matching platforms on road freight logistics firms. *Production and Operations Management* **31**(1) 117–137.

Zimmerman, Sarah. 2022. White house supply chain data exchange doubles in size. *https://www.supplychaindive.com/news/white-house-supply-chain-data-sharing-flow/629512/* .

Appendix

The appendix is organized as follows. The proofs for the analytical results on a single supply chain and competing supply chains are shown in §A and §B, respectively. Moreover, Lemma 4 (see §B.2) is a summary of every player's payoff expressions under different information arrangements.

A. Single Supply Chain

A.1. Proof of Proposition 1

Recall that Equation (7) gives the ex-ante payoffs for the various players under both partial and full information sharing, relative to the benchmark of no information sharing. Based on Equation (7) we obtain in the following inequalities:

$$\begin{aligned} &\Pi_R^{\mathtt{P}} - \Pi_R^{\mathtt{N}} > 0, \quad \Pi_M^{\mathtt{P}} - \Pi_M^{\mathtt{N}} < 0, \quad \Pi_P^{\mathtt{P}} - \Pi_P^{\mathtt{N}} > 0, \\ &\Pi_R^{\mathtt{F}} - \Pi_R^{\mathtt{N}} > 0, \quad \Pi_M^{\mathtt{F}} - \Pi_M^{\mathtt{N}} > 0, \quad \Pi_P^{\mathtt{F}} - \Pi_P^{\mathtt{N}} > 0, \end{aligned}$$

proving parts (a) and (b). Furthermore, it follows from Equation (7) that

$$\begin{aligned} \Pi_R^{\mathtt{F}} - \Pi_R^{\mathtt{P}} &= \frac{\eta\delta^2\xi^2}{(c+8)^2} - \frac{\eta\delta^2\xi^2}{16} &&= -\frac{(c+4)(c+12)\delta^2\xi^2\eta}{16(c+8)^2} < 0, \\ \Pi_M^{\mathtt{F}} - \Pi_M^{\mathtt{P}} &= \frac{\eta\delta^2\xi^2}{2(c+8)} + \frac{c\eta\delta^2\xi^2}{32} &&= \frac{(c+4)^2\delta^2\xi^2\eta}{32(c+8)} > 0, \\ \Pi_P^{\mathtt{F}} - \Pi_P^{\mathtt{P}} &= \frac{2\eta\delta^2\xi^2}{(c+8)^2} - \frac{\eta\delta^2\xi^2}{8} &&= -\frac{(c+4)(c+12)\delta^2\xi^2\eta}{8(c+8)^2} < 0, \end{aligned}$$

which completes the proof of part (c). □

A.2. Proof of Proposition 2

By Proposition 1, we know that relative to partial information sharing, full information sharing hurts the retailer and platform, but benefits the manufacturer. Hence, to induce full information sharing, the manufacturer offers the retailer and platform side payments, no less than $-(\Pi_R^{\mathtt{F}} - \Pi_R^{\mathtt{P}})$ and $-(\Pi_P^{\mathtt{F}} - \Pi_P^{\mathtt{P}})$, respectively. Accounting for these side payments, the manufacturer's net payoff under full information sharing is:

$$\Delta = [\Pi_R^{\mathtt{F}} - \Pi_R^{\mathtt{P}}] + [\Pi_M^{\mathtt{F}} - \Pi_M^{\mathtt{P}}] + [\Pi_P^{\mathtt{F}} - \Pi_P^{\mathtt{P}}] = \frac{(c-4)(c+4)(c+10)\delta^2\xi^2\eta}{32(c+8)^2}.$$

Hence, full information sharing is induced in the supply chain (i.e., $\Delta \geq 0$) only if $c \geq 4$; otherwise, partial information sharing is adopted. This proves part (a).

To prove part (b), we consider two cases. On the one hand, if $c \geq 4$, then full information sharing is adopted and the platform collects side payments $\Pi_P^{\mathtt{P}} - \Pi_P^{\mathtt{F}}$ from the manufacturer. Therefore, the platform's gross payoff is $\Pi_P^{\mathtt{N}} + \frac{2\eta\delta^2\xi^2}{(c+8)^2} + \left[\Pi_P^{\mathtt{P}} - \Pi_P^{\mathtt{F}}\right] = \Pi_P^{\mathtt{N}} + \frac{\eta\delta^2\xi^2}{8}$. On the other hand, if $c < 4$, then partial information sharing is adopted and the platform's gross payoff is $\Pi_P^{\mathtt{N}} + \frac{\eta\delta^2\xi^2}{8}$. □

A.3. Proof of Proposition 3

Recall from Equation (10) that the platform's problem of optimizing its information accuracy is:

$$\max_{a\geq 4}\Big\{\Pi^{\mathtt{N}}_P+\frac{\delta^2\xi^2}{8}\eta(a)-w(a)\Big\},$$

where $\eta(a):=\frac{(a-4)(\theta-1)^2\theta^2}{1+(a-4)(1-\theta)\theta}$ is concavely increasing in a. Since $w(a)$ is convex in a by assumption, it follows that the optimizer $a^*:=\arg\max_{a\geq 4}\{\Pi^{\mathtt{N}}_P+\frac{\delta^2\xi^2}{8}\eta(a)-w(a)\}$ is unique. Furthermore, it is straightforward to show that the objective function $\Pi^{\mathtt{N}}_P+\frac{\delta^2\xi^2}{8}\eta(a)-w(a)$ has the following properties:

- As a function of θ, the objective function is supermodular in $[0,\frac{1}{2}]$ and submodular in $[\frac{1}{2},1]$.
- As a function of δ, the objective function is (globally) supermodular.

These above structural properties the imply parts (a) and (b). Finally, when $w(a)$ has a linear form $w(a)=ka$, we apply the first order condition for optimality and obtain the expression $a^*=4+\big(\frac{\xi\delta}{\sqrt{8k}}-\frac{1}{(1-\theta)\theta}\big)^+$, as desired. By substituting a^* into every player's net payoff function (accounting the side payments), part (c) is proved by examining the derivatives of these net payoff functions with respect to δ. $\square$

B. Competing Supply Chains

B.1. Proof of Lemma 1

We first consider the case where both supply chains i and j adopt full information sharing. In this case, the Bayesian Nash equilibrium order quantities $(\hat{q}_i^{\mathtt{FF}},\hat{q}_j^{\mathtt{FF}})$ simultaneously satisfy the following system of equations:

$$q_i^{\mathtt{F}}(q_j)=\frac{u-r_c}{c+8}-\frac{G(\Upsilon)\delta\xi}{c+8}-\frac{\gamma\,\mathbb{E}\left[q_j\,|\,\Upsilon\right]}{c+8}\qquad\text{and}\qquad q_j^{\mathtt{F}}(q_i)=\frac{u-r_c}{c+8}-\frac{G(\Upsilon)\delta\xi}{c+8}-\frac{\gamma\,\mathbb{E}\left[q_i\,|\,\Upsilon\right]}{c+8}.$$

It is easy to verify that $\hat{q}_i^{\mathtt{FF}}=\hat{q}_j^{\mathtt{FF}}=\frac{u-r_c}{c+\gamma+8}-\frac{\delta\xi}{c+\gamma+8}G(\Upsilon)$ solves this system. Moreover, the uniqueness of $(\hat{q}_i^{\mathtt{FF}},\hat{q}_j^{\mathtt{FF}})$ can be proved following the techniques used in Claim 1 on page 579 of Ha et al. (2011). This completes the proof of the symmetric full information case. The Bayesian Nash equilibrium for the other cases can be similarly proved, and we omit the details here. $\square$

B.2. Every player's ex-ante payoffs in competing supply chains

Given the platform's information sharing strategy $\mathtt{Y}_i\in\{\mathtt{N},\mathtt{P},\mathtt{F}\}$ and $\mathtt{Y}_j\in\{\mathtt{N},\mathtt{P},\mathtt{F}\}$ for competing supply chains i and j, respectively, recall from §5 that $\Pi^{\mathtt{Y}_i}_{R_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{Y}_i})$ and $\Pi^{\mathtt{Y}_i}_{M_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{Y}_i})$ denote retailer i's and manufacturer i's ex-ante payoff in supply chain i. Furthermore, recall that $\Pi^{\mathtt{Y}_i}_{P_i}(\boldsymbol{\phi}_j^{\mathtt{Y}_j,\mathtt{Y}_i})$ denotes the platform's ex-ante payoff from retailer i. We define

$$\Pi^{\mathtt{NN}}_R:=\frac{(u-r_c-\xi\delta\theta)^2}{(c+\gamma+8)^2},\qquad\Pi^{\mathtt{NN}}_M:=\frac{(c+8)(u-r_c-\xi\delta\theta)^2}{2(c+\gamma+8)^2},\qquad\text{and}\qquad\Pi^{\mathtt{NN}}_P:=\frac{2(u-r_c-\xi\delta\theta)^2}{(c+\gamma+8)^2}.$$

The following result summarizes every player's ex-ante payoffs under the platform's different information sharing arrangements for a competing supply chain:

Lemma 4. *(a) If the platform does not share the freight information to either of the competing supply chains, i.e.,* $\mathtt{Y}_i = \mathtt{N}$ *and* $\mathtt{Y}_j = \mathtt{N}$*, then the players' ex-ante payoffs are as follows:*

$$\begin{aligned}
\Pi^{\mathtt{N}}_{R_i}(\boldsymbol{\phi}^{\mathtt{NN}}_j) &= \Pi^{\mathtt{N}}_{R_j}(\boldsymbol{\phi}^{\mathtt{NN}}_i) = \Pi^{\mathtt{NN}}_R,\\
\Pi^{\mathtt{N}}_{M_i}(\boldsymbol{\phi}^{\mathtt{NN}}_j) &= \Pi^{\mathtt{N}}_{M_j}(\boldsymbol{\phi}^{\mathtt{NN}}_i) = \Pi^{\mathtt{NN}}_M,\\
\Pi^{\mathtt{N}}_{P_i}(\boldsymbol{\phi}^{\mathtt{NN}}_j) &= \Pi^{\mathtt{N}}_{P_j}(\boldsymbol{\phi}^{\mathtt{NN}}_i) = \Pi^{\mathtt{NN}}_P.
\end{aligned}$$

Suppose that the platform shares the freight information to supply chain i, i.e., $\mathtt{Y}_i \in \{\mathtt{P}, \mathtt{F}\}$*, but does not share the information to supply chain j, i.e.,* $\mathtt{Y}_j = \mathtt{N}$*. Then the players' ex-ante payoffs relevant to supply chain i are as follows:*

$$\begin{aligned}
\Pi^{\mathtt{P}}_{R_i}(\boldsymbol{\phi}^{\mathtt{NP}}_j) &= \Pi^{\mathtt{NN}}_R + \frac{\eta\delta^2\xi^2}{16}, &\qquad \Pi^{\mathtt{F}}_{R_i}(\boldsymbol{\phi}^{\mathtt{NF}}_j) &= \Pi^{\mathtt{NN}}_R + \frac{\eta\delta^2\xi^2}{(c+8)^2},\\
\Pi^{\mathtt{P}}_{M_i}(\boldsymbol{\phi}^{\mathtt{NP}}_j) &= \Pi^{\mathtt{NN}}_M - \frac{c\eta\delta^2\xi^2}{32}, &\qquad \Pi^{\mathtt{F}}_{M_i}(\boldsymbol{\phi}^{\mathtt{NF}}_j) &= \Pi^{\mathtt{NN}}_M + \frac{\eta\delta^2\xi^2}{2(c+8)},\\
\Pi^{\mathtt{P}}_{P_i}(\boldsymbol{\phi}^{\mathtt{NP}}_j) &= \Pi^{\mathtt{NN}}_P + \frac{\delta^2\xi^2\eta}{8}, &\qquad \Pi^{\mathtt{F}}_{P_i}(\boldsymbol{\phi}^{\mathtt{NF}}_j) &= \Pi^{\mathtt{NN}}_P + \frac{2\delta^2\xi^2\eta}{(c+8)^2}
\end{aligned}$$

Meanwhile, the players' ex-ante payoff relevant to supply chain j are as follows:

$$\begin{aligned}
\Pi^{\mathtt{N}}_{R_j}(\boldsymbol{\phi}^{\mathtt{FN}}_i) &= \Pi^{\mathtt{N}}_{R_j}(\boldsymbol{\phi}^{\mathtt{PN}}_i) = \Pi^{\mathtt{NN}}_R,\\
\Pi^{\mathtt{N}}_{M_j}(\boldsymbol{\phi}^{\mathtt{FN}}_i) &= \Pi^{\mathtt{N}}_{M_j}(\boldsymbol{\phi}^{\mathtt{PN}}_i) = \Pi^{\mathtt{NN}}_M,\\
\Pi^{\mathtt{N}}_{P_j}(\boldsymbol{\phi}^{\mathtt{FN}}_i) &= \Pi^{\mathtt{N}}_{P_j}(\boldsymbol{\phi}^{\mathtt{PN}}_i) = \Pi^{\mathtt{NN}}_P.
\end{aligned}$$

(c) Suppose the platform shares the freight information to both supply chains, i.e., $\mathtt{Y}_i \in \{\mathtt{P}, \mathtt{F}\}$ *and* $\mathtt{Y}_j \in \{\mathtt{P}, \mathtt{F}\}$*. If the platform adopts partial information sharing to supply chain j, i.e.,* $\mathtt{Y}_j = \mathtt{P}$*, the players' ex-ante payoffs relevant to supply chain i are as follows:*

$$\begin{aligned}
\Pi^{\mathtt{P}}_{R_i}(\boldsymbol{\phi}^{\mathtt{PP}}_j) &= \Pi^{\mathtt{NN}}_R + \frac{\delta^2\xi^2\eta}{(\gamma+4)^2}, &\qquad \Pi^{\mathtt{F}}_{R_i}(\boldsymbol{\phi}^{\mathtt{PF}}_j) &= \Pi^{\mathtt{NN}}_R + \frac{(\gamma-4)^2\delta^2\xi^2\eta}{\left(\gamma^2-4(c+8)\right)^2},\\
\Pi^{\mathtt{P}}_{M_i}(\boldsymbol{\phi}^{\mathtt{PP}}_j) &= \Pi^{\mathtt{NN}}_M - \frac{c\delta^2\xi^2\eta}{2(\gamma+4)^2}, &\qquad \Pi^{\mathtt{F}}_{M_i}(\boldsymbol{\phi}^{\mathtt{PF}}_j) &= \Pi^{\mathtt{NN}}_M + \frac{(c+8)(\gamma-4)^2\delta^2\xi^2\eta}{2\left(\gamma^2-4(c+8)\right)^2},\\
\Pi^{\mathtt{P}}_{P_i}(\boldsymbol{\phi}^{\mathtt{PP}}_j) &= \Pi^{\mathtt{NN}}_P + \frac{2\delta^2\xi^2\eta}{(\gamma+4)^2}, &\qquad \Pi^{\mathtt{F}}_{P_i}(\boldsymbol{\phi}^{\mathtt{PF}}_j) &= \Pi^{\mathtt{NN}}_P + \frac{2(\gamma-4)^2\delta^2\xi^2\eta}{\left(\gamma^2-4(c+8)\right)^2}.
\end{aligned}$$

However, if the platform adopts full information sharing to supply chain j, i.e., $\mathtt{Y}_j = \mathtt{F}$*, the players' ex-ante payoffs relevant to supply chain i are as follows:*

$$\begin{aligned}
\Pi^{\mathtt{P}}_{R_i}(\boldsymbol{\phi}^{\mathtt{FP}}_j) &= \Pi^{\mathtt{NN}}_R + \frac{\delta^2\xi^2(c-\gamma+8)^2\eta}{\left(\gamma^2-4(c+8)\right)^2}, &\qquad \Pi^{\mathtt{F}}_{R_i}(\boldsymbol{\phi}^{\mathtt{FF}}_j) &= \Pi^{\mathtt{NN}}_R + \frac{\delta^2\xi^2\eta}{(c+\gamma+8)^2},\\
\Pi^{\mathtt{P}}_{M_i}(\boldsymbol{\phi}^{\mathtt{FP}}_j) &= \Pi^{\mathtt{NN}}_M - \frac{c\delta^2\xi^2(c-\gamma+8)^2\eta}{2\left(\gamma^2-4(c+8)\right)^2}, &\qquad \Pi^{\mathtt{F}}_{M_i}(\boldsymbol{\phi}^{\mathtt{FF}}_j) &= \Pi^{\mathtt{NN}}_M + \frac{(c+8)\delta^2\xi^2\eta}{2(c+\gamma+8)^2},\\
\Pi^{\mathtt{P}}_{P_i}(\boldsymbol{\phi}^{\mathtt{FP}}_j) &= \Pi^{\mathtt{NN}}_P + \frac{2\delta^2\xi^2(c-\gamma+8)^2\eta}{\left(\gamma^2-4(c+8)\right)^2}, &\qquad \Pi^{\mathtt{F}}_{P_i}(\boldsymbol{\phi}^{\mathtt{FF}}_j) &= \Pi^{\mathtt{NN}}_P + \frac{2\delta^2\xi^2\eta}{(c+\gamma+8)^2}.
\end{aligned}$$

Finally, the player's ex-ante payoffs relevant to supply chain j are obtained by reversing the roles of $\mathtt{Y}_i$ *and* $\mathtt{Y}_j$ *in the above equations.*

B.3. Proof of Lemma 2.

Lemma 2 is a direct result of Lemma 4. □

B.4. Proof of Lemma 3.

We discuss the direct effect, competitive effect, and spillover effect of full information sharing on every player in a supply chain i as follows.

(a) When the rival supply chain j has partial information sharing (i.e., $\texttt{Y}_j = \texttt{P}$), the direct effect of full information sharing on retailer i is $\Pi^{\texttt{F}}_{R_i}(\boldsymbol{\phi}_j^{\texttt{PP}}) - \Pi^{\texttt{P}}_{R_i}(\boldsymbol{\phi}_j^{\texttt{PP}}) = -\frac{(c+4)(c+12)\delta^2\eta\xi^2}{(c+8)^2(\gamma+4)^2} < 0$, and the direct effect on manufacturer i is $\Pi^{\texttt{F}}_{M_i}(\boldsymbol{\phi}_j^{\texttt{PP}}) - \Pi^{\texttt{P}}_{M_i}(\boldsymbol{\phi}_j^{\texttt{PP}}) = \frac{(c+4)^2\delta^2\eta\xi^2}{2(c+8)(\gamma+4)^2} > 0$. The competitive effect on retailer i is $\Pi^{\texttt{F}}_{R_i}(\boldsymbol{\phi}_j^{\texttt{PF}}) - \Pi^{\texttt{F}}_{R_i}(\boldsymbol{\phi}_j^{\texttt{PP}}) = \frac{(c+4)\gamma^2\delta^2\eta\xi^2((c+12)\gamma^2-32(c+8))}{(c+8)^2(\gamma+4)^2(\gamma^2-4(c+8))^2} < 0$, and the competitive effect on manufacturer i is $\Pi^{\texttt{F}}_{M_i}(\boldsymbol{\phi}_j^{\texttt{PF}}) - \Pi^{\texttt{F}}_{M_i}(\boldsymbol{\phi}_j^{\texttt{PP}}) = \frac{(c+4)\gamma^2\delta^2\eta\xi^2((c+12)\gamma^2-32(c+8))}{2(c+8)(\gamma+4)^2(\gamma^2-4(c+8))^2} < 0$. The overall effect on retailer i is $\Pi^{\texttt{F}}_{R_i}(\boldsymbol{\phi}_j^{\texttt{PF}}) - \Pi^{\texttt{P}}_{R_i}(\boldsymbol{\phi}_j^{\texttt{PP}}) = -\frac{8(c+4)\delta^2\eta\xi^2(-\gamma^2+2c+24)}{(\gamma+4)^2(\gamma^2-4(c+8))^2} < 0$, and the overall effect on manufacturer i is $\Pi^{\texttt{F}}_{M_i}(\boldsymbol{\phi}_j^{\texttt{PF}}) - \Pi^{\texttt{P}}_{M_i}(\boldsymbol{\phi}_j^{\texttt{PP}}) = \frac{(c+4)\delta^2\eta\xi^2(\gamma^4-4(c+8)\gamma^2+8(c+4)(c+8))}{(\gamma+4)^2(\gamma^2-4(c+8))^2} > 0$.

(b) When the rival supply chain j has full information sharing (i.e., $\texttt{Y}_j = \texttt{F}$), the direct effect on retailer i is $\Pi^{\texttt{F}}_{R_i}(\boldsymbol{\phi}_j^{\texttt{FP}}) - \Pi^{\texttt{P}}_{R_i}(\boldsymbol{\phi}_j^{\texttt{FP}}) = -\frac{(c+4)(c+12)\delta^2\eta\xi^2(c-\gamma+8)^2}{(c+8)^2(\gamma^2-4(c+8))^2} < 0$, and the direct on manufacturer i is $\Pi^{\texttt{F}}_{M_i}(\boldsymbol{\phi}_j^{\texttt{FP}}) - \Pi^{\texttt{P}}_{M_i}(\boldsymbol{\phi}_j^{\texttt{FP}}) = \frac{(c+4)^2\delta^2\eta\xi^2(c-\gamma+8)^2}{2(c+8)(\gamma^2-4(c+8))^2} > 0$. The competitive effect on retailer i is $\Pi^{\texttt{F}}_{R_i}(\boldsymbol{\phi}_j^{\texttt{FF}}) - \Pi^{\texttt{F}}_{R_i}(\boldsymbol{\phi}_j^{\texttt{FP}}) = -\frac{(c+4)\gamma^2\delta^2\eta\xi^2(8(c+8)^2-(c+12)\gamma^2)}{(c+8)^2(c+\gamma+8)^2(\gamma^2-4(c+8))^2} < 0$, and competitive effect on manufacturer i is $\Pi^{\texttt{F}}_{M_i}(\boldsymbol{\phi}_j^{\texttt{FF}}) - \Pi^{\texttt{F}}_{M_i}(\boldsymbol{\phi}_j^{\texttt{FP}}) = -\frac{(c+4)\gamma^2\delta^2\eta\xi^2(8(c+8)^2-(c+12)\gamma^2)}{2(c+8)(c+\gamma+8)^2(\gamma^2-4(c+8))^2} < 0$. The overall effect on retailer i is $\Pi^{\texttt{F}}_{R_i}(\boldsymbol{\phi}_j^{\texttt{FF}}) - \Pi^{\texttt{P}}_{R_i}(\boldsymbol{\phi}_j^{\texttt{FP}}) = -\frac{(c+4)(c+8)\delta^2\eta\xi^2(96-2\gamma^2+c(c+20))}{(c+\gamma+8)^2(\gamma^2-4(c+8))^2} < 0$, and the overall effect on manufacturer i is $\Pi^{\texttt{F}}_{M_i}(\boldsymbol{\phi}_j^{\texttt{FF}}) - \Pi^{\texttt{P}}_{M_i}(\boldsymbol{\phi}_j^{\texttt{FP}}) = \frac{(c+4)\delta^2\eta\xi^2(2\gamma^4-2(c+8)^2\gamma^2+(c+4)(c+8)^3)}{2(c+\gamma+8)^2(\gamma^2-4(c+8))^2} > 0$

Next, we discuss the direct, competitive, and spillover effect of full information sharing on the platform.

(c) When the rival supply chain j has partial information sharing (i.e., $\texttt{Y}_j = \texttt{P}$), the direct effect on the platform is $\Pi^{\texttt{F}}_{P_i}(\boldsymbol{\phi}_j^{\texttt{PP}}) - \Pi^{\texttt{P}}_{P_i}(\boldsymbol{\phi}_j^{\texttt{PP}}) = -\frac{2(c+4)(c+12)\delta^2\eta\xi^2}{(c+8)^2(\gamma+4)^2} < 0$. The competitive effect on the platform is $\Pi^{\texttt{F}}_{P_i}(\boldsymbol{\phi}_j^{\texttt{PF}}) - \Pi^{\texttt{F}}_{P_i}(\boldsymbol{\phi}_j^{\texttt{PP}}) = \frac{2(c+4)\gamma^2\delta^2\eta\xi^2((c+12)\gamma^2-32(c+8))}{(c+8)^2(\gamma+4)^2(\gamma^2-4(c+8))^2} < 0$. The spillover effect on the platform is $\Pi^{\texttt{P}}_{P_j}(\boldsymbol{\phi}_i^{\texttt{FP}}) - \Pi^{\texttt{P}}_{P_j}(\boldsymbol{\phi}_i^{\texttt{PP}}) = \frac{2(c+4)\gamma\delta^2\eta\xi^2(c(\gamma+8)-2(\gamma-2)\gamma+64)}{(\gamma+4)^2(\gamma^2-4(c+8))^2} > 0$. The overall effect on the platform is

$$\left[\Pi^{\texttt{F}}_{P_i}(\boldsymbol{\phi}_j^{\texttt{PF}}) + \Pi^{\texttt{P}}_{P_j}(\boldsymbol{\phi}_i^{\texttt{FP}})\right] - \left[\Pi^{\texttt{P}}_{P_i}(\boldsymbol{\phi}_j^{\texttt{PP}}) + \Pi^{\texttt{P}}_{P_j}(\boldsymbol{\phi}_i^{\texttt{PP}})\right] = \frac{2(c+4)\delta^2\eta\xi^2\big((c+12)\gamma^2-2\gamma^3+8(c+8)\gamma-16(c+12)\big)}{(\gamma+4)^2(\gamma^2-4(c+8))^2} < 0.$$

(d) When the rival supply chain j has full information sharing (i.e., $\texttt{Y}_j = \texttt{F}$), the direct effect is $\Pi^{\texttt{F}}_{P_i}(\boldsymbol{\phi}_j^{\texttt{FP}}) - \Pi^{\texttt{P}}_{P_i}(\boldsymbol{\phi}_j^{\texttt{FP}}) = -\frac{2(c+4)(c+12)\delta^2\eta\xi^2(c-\gamma+8)^2}{(c+8)^2(\gamma^2-4(c+8))^2} < 0$. The competitive effect is $\Pi^{\texttt{F}}_{P_i}(\boldsymbol{\phi}_j^{\texttt{FF}}) - \Pi^{\texttt{F}}_{P_i}(\boldsymbol{\phi}_j^{\texttt{FP}}) = -\frac{2(c+4)\gamma^2\delta^2\eta\xi^2\big(8(c+8)^2-(c+12)\gamma^2\big)}{(c+8)^2(c+\gamma+8)^2(\gamma^2-4(c+8))^2} < 0$. The spillover effect is $\Pi^{\texttt{F}}_{P_j}(\boldsymbol{\phi}_i^{\texttt{FF}}) - \Pi^{\texttt{F}}_{P_j}(\boldsymbol{\phi}_i^{\texttt{PF}}) = \frac{2(c+4)\gamma\delta^2\eta\xi^2(c(8-\gamma)-2\gamma(\gamma+2)+64)}{(c+\gamma+8)^2(\gamma^2-4(c+8))^2} > 0$. The overall effect on the platform is

$$\left[\Pi^{\texttt{F}}_{P_i}(\boldsymbol{\phi}_j^{\texttt{FF}}) + \Pi^{\texttt{F}}_{P_j}(\boldsymbol{\phi}_i^{\texttt{FF}})\right] - \left[\Pi^{\texttt{P}}_{P_i}(\boldsymbol{\phi}_j^{\texttt{FP}}) + \Pi^{\texttt{F}}_{P_j}(\boldsymbol{\phi}_i^{\texttt{PF}})\right] = -\frac{2(c+4)\delta^2\eta\xi^2\big(2\gamma^3-(c+12)\gamma^2-8(c+8)\gamma+(c+8)^2(c+12)\big)}{(c+\gamma+8)^2(\gamma^2-4(c+8))^2} < 0,$$

which completes the proof. □

Proof of Proposition 4

To obtain the equilibrium information sharing arrangement in two competing supply chains, we first explore the conditions for the adoption of different information sharing strategies as follows.

(a) When the rival supply chain j has partial information sharing, based on Lemma 4, we have:

$$\begin{aligned}
&\Pi^{\mathsf{F}}_{R_i}(\boldsymbol{\phi}^{\mathsf{PF}}_j) - \Pi^{\mathsf{P}}_{R_i}(\boldsymbol{\phi}^{\mathsf{PP}}_j) = -\frac{8(c+4)\delta^2\xi^2(24-\gamma^2+2c)\eta}{(\gamma+4)^2(\gamma^2-4(c+8))^2} < 0,\\
&\Pi^{\mathsf{F}}_{M_i}(\boldsymbol{\phi}^{\mathsf{PF}}_j) - \Pi^{\mathsf{P}}_{M_i}(\boldsymbol{\phi}^{\mathsf{PP}}_j) = \frac{(c+4)\delta^2\xi^2(\gamma^4-4(c+8)\gamma^2+8(c+4)(c+8))\eta}{(\gamma+4)^2(\gamma^2-4(c+8))^2} > 0,\\
&(\Pi^{\mathsf{F}}_{P_i}(\boldsymbol{\phi}^{\mathsf{PF}}_j) + \Pi^{\mathsf{P}}_{P_j}(\boldsymbol{\phi}^{\mathsf{FP}}_i)) - (\Pi^{\mathsf{P}}_{P_i}(\boldsymbol{\phi}^{\mathsf{PP}}_j) + \Pi^{\mathsf{P}}_{P_j}(\boldsymbol{\phi}^{\mathsf{PP}}_i)) = \frac{2(c+4)\delta^2\xi^2((c+12)\gamma^2-2\gamma^3+8(c+8)\gamma-16(c+12))\eta}{(\gamma+4)^2(\gamma^2-4(c+8))^2} < 0.
\end{aligned}$$

Hence, manufacturer i has to offer side payments to retailer i and the platform to offset their losses. Accounting for the side payments, the manufacturer's net payoff is given by:

$$\begin{aligned}
\Delta_1 &= (\Pi^{\mathsf{F}}_{P_i}(\boldsymbol{\phi}^{\mathsf{PF}}_j) + \Pi^{\mathsf{P}}_{P_j}(\boldsymbol{\phi}^{\mathsf{FP}}_i)) - (\Pi^{\mathsf{P}}_{P_i}(\boldsymbol{\phi}^{\mathsf{PP}}_j) + \Pi^{\mathsf{P}}_{P_j}(\boldsymbol{\phi}^{\mathsf{PP}}_i)) + (\Pi^{\mathsf{F}}_{R_i}(\boldsymbol{\phi}^{\mathsf{PF}}_j) - \Pi^{\mathsf{P}}_{R_i}(\boldsymbol{\phi}^{\mathsf{PP}}_j)) + (\Pi^{\mathsf{F}}_{M_i}(\boldsymbol{\phi}^{\mathsf{PF}}_j) - \Pi^{\mathsf{P}}_{M_i}(\boldsymbol{\phi}^{\mathsf{PP}}_j))\\
&= \frac{(c+4)\delta^2\eta\xi^2\left(\gamma^4-4\gamma^3-2c\gamma^2+16(c+8)\gamma+8(c-4)(c+10)\right)}{(\gamma+4)^2(\gamma^2-4(c+8))^2},
\end{aligned}$$

which is non-negative if $h_1(c) = \gamma^4 - 4\gamma^3 - 2c\gamma^2 + 16(c+8)\gamma + 8(c-4)(c+10) \geq 0$. Note that the function $h_1(c)$ crosses the zero line from negative to positive only once and thus has unique zero point $\hat{c}^{\mathsf{PP}}$ for $h_1(c) = 0$. In summary, $\Delta_1 \geq 0$ when $c \geq \hat{c}^{\mathsf{PP}}$.

Thus, we conclude that when the rival supply chain j has partial information sharing, if $\delta > \hat{\delta}^{\mathsf{PP}}$, then full information sharing is induced in supply chain i; otherwise, partial information sharing is adopted. Moreover, $\hat{\delta}^{\mathsf{PP}} < 1$ if $c > \hat{c}^{\mathsf{PP}}$, and $\hat{\delta}^{\mathsf{PP}} \geq 1$ if $c \geq \hat{c}^{\mathsf{PP}}$. It is easy to verify that $\hat{c}^{\mathsf{PP}}$ is decreasing in γ, and $\hat{\delta}^{\mathsf{PP}}$ is also decreasing in γ for $c > \hat{c}^{\mathsf{PP}}$.

(b) When the rival supply chain j has full information sharing, from Lemma 4 we also have:

$$\begin{aligned}
&\Pi^{\mathsf{F}}_{R_i}(\boldsymbol{\phi}^{\mathsf{FF}}_j) - \Pi^{\mathsf{P}}_{R_i}(\boldsymbol{\phi}^{\mathsf{FP}}_j) = -\frac{(c+4)(c+8)\delta^2\xi^2(96-2\gamma^2+c(c+20))\eta}{(c+\gamma+8)^2(\gamma^2-4(c+8))^2} < 0,\\
&\Pi^{\mathsf{F}}_{M_i}(\boldsymbol{\phi}^{\mathsf{FF}}_j) - \Pi^{\mathsf{P}}_{M_i}(\boldsymbol{\phi}^{\mathsf{FP}}_j) = \frac{(c+4)\delta^2\xi^2(2\gamma^4-2(c+8)^2\gamma^2+(c+4)(c+8)^3)\eta}{2(c+\gamma+8)^2(\gamma^2-4(c+8))^2} > 0,\\
&(\Pi^{\mathsf{F}}_{P_i}(\boldsymbol{\phi}^{\mathsf{FF}}_j) + \Pi^{\mathsf{F}}_{P_j}(\boldsymbol{\phi}^{\mathsf{FF}}_i)) - (\Pi^{\mathsf{P}}_{P_i}(\boldsymbol{\phi}^{\mathsf{FP}}_j) + \Pi^{\mathsf{P}}_{P_j}(\boldsymbol{\phi}^{\mathsf{PF}}_i)) = -\frac{2(c+4)\eta\delta^2\xi^2\left(2\gamma^3-(c+12)\gamma^2-8(c+8)\gamma+(c+8)^2(c+12)\right)}{(c+\gamma+8)^2(\gamma^2-4(c+8))^2} < 0.
\end{aligned}$$

Hence, manufacturer i has to offer the retailer i and the platform with side payments to offset their losses. As a result, the manufacturer's net payoff is

$$\begin{aligned}
\Delta_2 &= (\Pi^{\mathsf{F}}_{P_i}(\boldsymbol{\phi}^{\mathsf{FF}}_j) + \Pi^{\mathsf{F}}_{P_j}(\boldsymbol{\phi}^{\mathsf{FF}}_i)) - (\Pi^{\mathsf{P}}_{P_i}(\boldsymbol{\phi}^{\mathsf{FP}}_j) + \Pi^{\mathsf{P}}_{P_j}(\boldsymbol{\phi}^{\mathsf{PF}}_i)) + (\Pi^{\mathsf{F}}_{R_i}(\boldsymbol{\phi}^{\mathsf{FF}}_j) - \Pi^{\mathsf{P}}_{R_i}(\boldsymbol{\phi}^{\mathsf{FP}}_j)) + (\Pi^{\mathsf{F}}_{M_i}(\boldsymbol{\phi}^{\mathsf{FF}}_j) - \Pi^{\mathsf{P}}_{M_i}(\boldsymbol{\phi}^{\mathsf{FP}}_j))\\
&= \frac{(c+4)\delta^2\eta\xi^2\left(2\gamma^4-8\gamma^3-2(c(c+12)+24)\gamma^2+32(c+8)\gamma+(c-4)(c+8)^2(c+10)\right)}{2(c+\gamma+8)^2(\gamma^2-4(c+8))^2}.
\end{aligned}$$

which is non-negative if $h_2(c) = 2\gamma^4 - 8\gamma^3 - 2(c(c+12)+24)\gamma^2 + 32(c+8)\gamma + (c-4)(c+8)^2(c+10)$. Note that the function $h_2(c)$ crosses the zero line from negative to positive only once and thus has a unique zero point $\hat{c}^{\mathsf{FF}}$ for $h_2(c) = 0$. In summary, $\Delta_2 \geq 0$ when $c \geq \hat{c}^{\mathsf{FF}}$.

It is easy to verify that $\hat{c}^{\mathsf{PP}} < \hat{c}^{\mathsf{FF}}$. Based on the above conditions, we discuss the platform's equilibrium information sharing strategies for competing supply chains as follows.

(1) if $c \geq \hat{c}^{\mathsf{FF}}$, then a focal supply chain will adopt full information sharing no matter regardless of rival supply chain's information arrangement. Thus, the unique NE is $(\mathtt{F}, \mathtt{F})$;

(2) if $\hat{c}^{\mathsf{PP}} < c < \hat{c}^{\mathsf{FF}}$, then a focal supply chain will adopt full/partial information sharing as the rival supply chain adopt partial/full information sharing. In this case, $(\mathtt{P}, \mathtt{F})$ and $(\mathtt{F}, \mathtt{P})$ are two possible equilibria;

(3) if $c \leq \hat{c}^{\mathsf{PP}}$, then a focal supply chain will adopt partial information sharing regardless of rival supply chain's information arrangement. Thus, the unique NE is $(\mathtt{P}, \mathtt{P})$.

The platform's ex-ante net playoffs under each equilibrium information sharing strategies can be obtained based on Lemma 4. □

Proof of Proposition 5

The proof of Proposition 5 is similar to that of Proposition 3. The detailed proof is omitted here. □