An Information Sharing Framework for Supply Chain Networks: What, When, and How to Share

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Abstract. In decentralized supply chains, firms often deal with asymmetric information. One company's private information can be relevant for the other company to make better decisions. Therefore, what to share, when to reveal, and how to share the information are of interest. There has been an increasing interest in supply chain coordination issues under asymmetric information in the past two decades. However, few of them consider strategic information sharing among the supply chain members. Thus, this paper aims to review the development of information sharing in supply chain management. We classify the existing literature into three categories, namely (i) supply chain coordination under information asymmetry, (ii) information sharing technologies, and (iii) a strategic information sharing framework regarding what, when, and how to share. The related supply chain literature is reviewed based on the different focuses when dealing with information asymmetry. We report the research development and gaps of each category. Further, we propose some future research directions based on the findings from the literature review.

Keywords: Information Sharing · Game Theory · Asymmetric Information · Information Sharing Technologies · Literature Review

1 Introduction

Nowadays, companies can access abundant data and share precise information with their supply chain members. As competition and interaction are intensified across horizontal and vertical supply chains, the decision to share information is more intricate than ever [50]. In a decentralized supply chain, asymmetric information can lead to a significant efficiency loss [37]. Hence, the right use of available information has become an indispensable factor for a company to sustain its competitiveness [23].

Even though empirical evidence shows that information sharing can be a means of supply chain coordination, strategic information sharing is still challenging for supply chain members [13]. The main reason is the reluctance of the members to share information due to the threat of information leakage and opportunistic behaviors [28]. Further, supply chain members possess different types of private information such as demand, costs, capacity, and inventory. This private information is rarely accessible to the other supply chain members; however, it still directly or indirectly influences each member's performance [34].

Due to its importance but challenging nature, information sharing issues have gained significant attention in the supply chain management (SCM) area [13, 8, 50, 53]. Their focus is mainly on coordination mechanism designs such as a menu of contracts and side payments, given that one member in the supply chain has prior access to certain information. Most of the literature in this field knows what to be shared and investigates how to make the party that possesses the private information reveal it with contractual agreements.

Another way of dealing with information sharing issues is advanced information sharing technology such as cryptographic techniques [18]. In this field, actors focus on secure sharing or even cooperation without revealing private information to each other. The literature on information sharing technologies aims to develop collaboration supporting applications/environments among actors willing to share information (even if it is not truthful) [53]. This stream of literature knows what to share and focuses on how to (securely) share the information.

While increasing attention has been given to information sharing, few authors focus on the impact of different sharing behaviors on performance. However, in many cases, a decision requires different sets of another member's private information, and the decision eventually influences the other's performance. Thus, a strategic information sharing framework that answers what, when, and how to share information is highly relevant. To better understand strategic information sharing issues, we review the development of information sharing in SCM with respect to the three categories of information sharing: (i) supply chain coordination under information asymmetry, (ii) information sharing technologies, and (iii) strategic information sharing framework regarding what, when, and how to share.

2 Literature Review

For a systematic literature review, we followed [52] and employed the keywords: information sharing, asymmetric information, incomplete information, secure sharing, information security, private information, strategic sharing, and supply chain. The sources of data included Google Scholar, Springer, ScienceDirect.

2.1 Coordination under Asymmetric Information

We refer to [13, 8, 28, 50, 53] for general reviews. We classify the literature depending on asymmetric information types, the two most common being demand and cost information. Even though other types of asymmetric information such as quality, capacity, and effort level exist, the number of literature is significantly lower than that on demand and cost information [50]. Therefore, we focus on these two types.

Demand information of retailers often influences the capacity decision of suppliers. [9] consider a single supplier and multiple retailers who compete for scarce supplier capacity. The private information is the demand-based order quantities of the retailers. They demonstrate that the truth-telling mechanisms may not result in maximum profits for the supplier and the retailers. Later, [10] suggest two capacity compliance contracts that realize truthful demand forecast sharing. Unlike [9], they consider a monopolistic setting with one supplier and one manufacturer. [43] also consider a supplier who makes a capacity decision and a manufacturer who possesses precise demand forecast information. Compared to the previous literature mainly focusing on the screening mechanisms for truth-telling, they develop both signaling (advance purchase) and screening (capacity reservation) mechanisms for credible information sharing.

[49] extend a single period incentive alignment problem to multiple periods. Over repeating selling seasons, the supplier offers a simple contract if the demand information is observed. Otherwise, the supplier designs a truth-telling contract for the manufacturer. He concludes that the manufacturer is worse-off when a simple contract is offered. While most of the literature decides either price or quantity based on the available information, [17] propose a dual decision-making contract where the manufacturer decides both the capacity and the wholesale price. The dual decisions that are influenced oppositely by the demand information reduce the retailer's incentive to distort the information. While most of the literature considers an intra-firm relationship, [3, 45, 14, 36] study inter-firm situations where a manager tries to incentivize salesforces to disclose market information.

Asymmetric cost information has received as much attention as demand information [50]. [21] consider asymmetric cost information and develop a quantity discount contract under asymmetric cost information. They extend to two-part linear schemes and two-part nonlinear schemes introduced earlier by [20]. Quantity discounts are the most frequently applied mechanisms to achieve supply chain coordination between one member who possesses private information and the other who offers the contract [51, 32, 60]. Another common mechanism is the menu of contracts. The conceptual foundation of both contracts lies in the revelation principle [41, 56, 11, 33, 24, 39]. To model asymmetric information, [11, 39] apply a two-point distribution. On the other hand, [41, 56, 33, 24] assume that the belief in cost follows a certain distribution. While the contract design is an effective means of coordinating supply chains [53], [40, 7, 31] introduce auctions as a coordination mechanism.

Whereas most literature considers a single source of asymmetric information, [38, 6] consider two or more sources. [38] use a menu of contracts for the supplier, where the disruption risks of demand and cost are the retailer's private information. [6] consider multiple suppliers with private capacity information and multiple retailers with private demand information. Instead of introducing a contract design mechanism, they compare two bargaining power structures between downstream (pooling systems) and upstream (distribution system) members. They conclude that multilateral information asymmetry only harms the efficiency of the supply chain if the upstream principal distributes resources across multiple downstream agents. [34] study a supplier and an original equipment manufacturer (OEM) relationship where the OEM has two private information sets: demand and production cost. Interestingly, they find that the conventional contract design, such as the menu of contracts, cannot incentivize the retailer to reveal truthful information when there are two sets of asymmetric information.

2.2 Information Sharing Technologies

The technical perspective of secure sharing attracts growing attention while entering the era of big data and leaves future research directions integrated with the classic information asymmetric issues. Companies nowadays actively search for new technologies to share information on time and synchronize information flows with other companies [26]. At the same time, the companies' concerns about privacy and information security grow. In this study, we specifically investigate cryptographic technology such as blockchain and secure multiparty computation (SMC), the main concern of which is secure information sharing.

Blockchain technology gained popularity in computer science after [42] introduced the cryptocurrency Bitcoin. Whilst the most commonly known application of blockchain technology is cryptocurrency, blockchain technology for commodity trading and asset tracking shows its promising future [29]. Despite the slow adaptation of technology in the SCM field, [35] assert that blockchain can improve the transparency, traceability, and efficiency of sharing information. [55, 12] give a review of blockchain and propose several future agendas in SCM. For instance, [55] suggest the integration of blockchain technology with IoT-based supply chains. As the number of IoT devices rises, blockchain can be a solution to store an excessive amount of generated data from IoT. On the other hand, [12] highlight technical challenges of blockchain application such as trustfulness, lack of standards, and interoperability.

Even though most papers are conceptual reviews and examine future potentials [46, 47], a few quantify the benefit of blockchain technology for supply chain performance. [58] apply the technology in a global trade context with air and ocean shipping. They introduce mathematical models where the benefit of blockchain comes with the accuracy of prediction and reduced operational costs. Further, [22] use a game theoretic framework. They demonstrate that blockchain is not always preferred to the traditional platform as they have to consider the tradeoffs between implementation costs of blockchain and gained efficiency. However, with the help of two smart contracts (wholesale price and revenue sharing), the blockchain application can lead to better performance. [58, 22] consider blockchain technology in their economic models. [15] suggest a blockchain protocol, b_verify (a Bitcoin network), and present an implementation that measures the signaling costs of a firm's quality and demonstrate that, due to the transparency, the company can secure lower signaling costs.

Whereas the main benefit of blockchain is the transparency of the information, SMC emphasizes privacy protection. [57] propose a mechanism for secure function evaluation by using garbled circuits. The garbled circuit is one of the first and best-known SMC methods aligned with secret sharing [48] and homomorphic encryption (HE) [16]. A given condition of these three methods is the assumption of honest-but-curious (semi-honest) players. In the SCM field, we find several attempts at applying SMC concepts to share private information. [2], for example, introduce SMC algorithms based on Yao's protocol [57] to allocate the capacity in e-commerce. [1] develop a protocol for secure collaborative forecasting and replenishment (SCPFR) decisions. They both use secret sharing and HE approaches. They are the first to consider inverse optimization issues in SMC. [18] propose a secure mechanism to optimize task swaps of independent trucking companies reluctant to share their current pick-up and delivery schedules. The suggested method allows truck companies to exchange their pick-up and delivery tasks without revealing more information than necessary to execute the exchanged task. [44] also use the garbled circuit to solve the Joint Economic Lot-Sizing (JELS) problem and show the efficiency of SMC to share profits.

2.3 Strategic Information Sharing Framework

The literature on strategic information sharing is relatively scarce. While information sharing itself is a rising topic in the SCM area, only a few offer information exchange strategies for scenarios where the others also share/ do not share. [54] investigate the ramification of sharing a retailer's private information with a supplier with prior knowledge from a subjective distribution. They elaborate on the advantages and disadvantages that the retailer faces under different contract schemes by letting the supplier improve knowledge. However, they assume that the private information is held by the retailer only; hence, the information exchange between the supply chain members is not considered. [59] consider both a retailer and a supplier that possess partial demand information. Under a wholesale price contract, they find that sharing occurs based on the variance and the correlation of demand information between the companies and the other company's sharing behavior. Besides, they suggest that a revenue sharing contract can coordinate the system while ensuring information sharing from both firms. [27] investigate sharing behavior of retailers who possess private demand information. They include two competing channels and analyze the impact of competition on the sharing strategy. They propose an information sharing framework that suggests when to share the information with their upstream manufacturers to induce lower wholesale prices. However, they, too, are limited in that they only consider unilateral private information.

3 Results and Implications

From the literature regarding information sharing, we observe the following:

- What to share is exogenously given in the problems
- How to share unilateral information is comprehensively investigated. However, the literature on how to share bi/multilateral information is scarce

- When to share throughout the relationship in a supply chain network is rarely covered

In the information sharing literature, as the type of asymmetric information is set exogenously, the question of what to share is often disregarded. The most common consideration of asymmetric information in the existing literature is either cost or demand. The reason is that most analytical models seek to maximize profit or minimize cost. Having demand or cost as private information facilitates the analysis to observe the impact of asymmetric information on the supply chain performance. However, supply chain members can learn which type of information to reveal over some periods. As most of the literature considers unilateral (bilateral) asymmetric information and the rest of the information in supply chains as common knowledge, endogenizing what to share can be a future research direction.

Further, there is a lack of dual (multiple) information sharing in SCM. A significant proportion of the problems is modeled under a Stackelberg game framework where a leader needs to decide under unilateral information asymmetry. However, it is questionable whether the existing mechanisms can still be efficient under multiple asymmetric information [34]. Moreover, the multilateral/bilateral exchange of information itself can impact the performance of the supply chain members. For example, a manufacturer's capacity decision is often based on the market demands that are the private information of retailers and the production cost of manufacturers. Since the manufacturer's capacity level directly affects the retailer's performance, the retailer is eager to know how and based on what available information the capacity is set. From the supplier's perspective, the more precise he knows demand, the better he can plan. Knowing that the retailer is interested in his capacity decision, he can strategically reveal which information he knows. In this regard, more attention is needed to answer when and how to exchange information under consideration of bilateral or multilateral asymmetric information.

Whereas mechanism designs seek to answer how to make private information be shared, the information sharing technology aims to answer how to securely and efficiently share private information. Especially, blockchain technology is promising because it can be a solution for truthful information sharing. At the same time, SMC can provide a new opportunity by encouraging reluctant supply chain members to cooperate securely. However, reverse optimization and technical security problems still need to be solved before further applications can be realized. Lastly, the research on information sharing technologies often assumes honest-but-curious players. However, this assumption does not take the impact of information distortion into account. Hence, another research direction can integrate truth-telling mechanisms from the supply chain coordination literature and cryptographic technologies. With the right use of information mechanisms, firms can secure private information and avoid suboptimal decisions from information asymmetry.

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