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# Supply chain transparency as a signal of ethical production

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## Abstract

We analyze firms' supply chain transparency and ethical production practices using a game-theoretic approach. If the rival's supply chain is more likely to be ethical and the technology used to ensure supply chain transparency is efficient, ethical suppliers prefer to disclose their supply chain information, whereas unethical suppliers do not. The supply chain transparency level can be a signal of the supplier's ethical quality level, as both consumers' demand for ethical production and R&D efficiency for supply chain transparency increase. Consumers can distinguish ethical suppliers through their level of supply chain transparency because blockchain technology improves R&D efficiency.

JEL CLASSIFICATION
D21, L15, M11, Q56

## 1 | INTRODUCTION

As contact-free transactions increase with the COVID-19 pandemic era, supply chain management is becoming more important than before. Accordingly, interest in efficient and safe supply chain management has also increased. Supply chain transparency, which is crucial for the efficient and safe management of the supply chain, is generally defined as disclosing supply chain information such as resources, manufacturing processes, and logistics to other supply chain participants or consumers. Supply chain transparency is known by different terms, including visibility and traceability, each with differing explanations. Nonetheless, the key concept is to gain trust by disclosing information (Montecchi et al., 2021).

Sharing supply chain information among participants (i.e., ensuring a transparent supply chain) not only mitigates information asymmetry across the supply chain (Cohen & Klepper, 1996; Fiala, 2005; Lin & Saggi, 2002) but also prevents the risk of working with fraudulent business partners. In addition, a transparent supply chain improves the efficiency of responses to problems. Transparently disclosing process information makes it easy to find the liability; hence, the spread of damage can be quickly identified and addressed (Hobbs, 2004). For these reasons, research on supply chain transparency has mainly been from the perspective of efficient management, with the aim of finding technologies and systems that can efficiently implement supply chain transparency (Kim et al., 2011; Kulkarni, 2000).

Supply chain transparency can also increase consumers' trust in suppliers. Consumers search for product information before purchasing and make purchase decisions by examining the utility of an item. Supply chain transparency has traditionally been unrelated to consumers because of the high cost they have paid to find product information. However, the development of information technology has reduced consumers' search costs, meaning that they can now easily access supply chain information. Hence, supply chain transparency has a greater impact on consumers than before. The emergence of ethical consumerism is further reinforcing the tendency of consumers to be sensitive to supply chain transparency. Ethical consumers choose against unethical suppliers that unfairly exploit workers or harm the environment through their manufacturing and logistics processes (Ahmed & Machold, 2004). Thus, disclosing supply chain information can raise profits. However, increasing supply chain transparency can also lower a company's sales and damage its reputation, especially given the recent increase in consumers' ethical standards. Thus, suppliers may be reluctant to disclose information on their supply chains (Mishra et al., 1998; Vinning & Weimer, 1988; Zhang et al., 2014).

Duan and Aloysius (2019) claimed that consumers tend to place more weight on ethical production processes than on such traditional product selection criteria as product price and quality. In other words, no matter how high the product quality is, if it was produced through an unethical process (e.g., the exploitation of labor or environmental destruction in the manufacturing and logistics processes), consumer demand may decrease. Thus, we assume the following two propositions. First, product quality is a broad concept that encompasses consumers' ethical standards. We denote this quality concept as “ethical quality.” Second, product quality disclosed according to the supply chain transparency level affects demand. Under these assumptions, we adopt a simple economic model to show that supply chain transparency can be a signal of product quality.

We analyze whether and to what degree companies choose to improve their supply chain transparency. We describe the situation in which companies adopt a technology to improve supply chain transparency using a game-theoretic model. Since a new system must be introduced to improve supply chain transparency, this decision problem is similar to analyzing research and development (R&D) decisions. We therefore analyze firms' supply chain transparency decisions by referencing an R&D decision model. Our model extends the R&D game-theoretic model developed by Brander and Spencer (1983). We combine the concepts of R&D studies and supply chain transparency studies. We assume that two distinct firms compete on R&D for supply chain transparency and that consumers prefer ethical production methods. Modifying the consumer utility function of Park and Ryu (2022), we derive stochastic demand based on consumers' preference for an ethical supply chain. Our model confirms that peach firms raise their transparency level and lemon firms lower their transparency level, as the probability that the rival is a peach firm and the efficiency of technology for supply chain transparency is higher.[1] This implies that as both consumers' demand for ethical production and R&D efficiency for supply chain transparency increase, the supply chain transparency level can be a signal of the supplier's ethical quality level.

Our results show that adopting an efficient technology to disclose information provides a clearer signal of ethical production. Using two case studies, we suggest blockchain as information technology for improving supply chain transparency, as it is tamper-proof and can provide reliable records to consumers. In addition, blockchain technology enables efficient supply chain management by incorporating other technologies such as smart contracts, radio-frequency identification (RFID), and the Internet of Things (IoT). We introduce cases of firms in the food industry and automobile industry adopting blockchain technology to disclose their supply chain information. These case studies show that disclosing supply chain information raises their ethical quality.

This study makes three main contributions to the existing literature. First, we show that firms can use supply chain transparency as a sustainable business strategy. Second, we analyze firms' decisions on supply chain transparency according to their quality type. Third, our result suggests that blockchain technology can provide supply chain transparency, thereby demonstrating the unbiased feasibility of industry-wide applications of such technology.

The remainder of this paper is organized as follows. Section 2 develops the game-theoretic model of supply chain transparency and shows the results. Section 3 suggests blockchain technology as a good candidate for disclosing supply chain information using two case studies. Finally, Section 4 concludes by providing a summary and the strategic implications of our findings.

## 2 | SUPPLY CHAIN TRANSPARENCY AS A SIGNAL OF ETHICAL PRODUCTION

### 2.1 | Model design

Using a game theory approach, we describe firms' strategies for setting their supply chain transparency levels. Two suppliers ($X$ and $Y$) exist in the market, and they produce homogeneous products. Their products have the same quality, and the market price of the products is 1. However, the final products differ in whether the suppliers produce their products through an ethical supply chain. A supply chain is ethical with a probability $p$ and unethical with a probability $1-p$. Suppliers choose their supply chain transparency levels simultaneously based on their ethical quality levels.

Consumers ($i=1,\ldots,N$) buy the product that provides them with higher utility. The utility function of a consumer on product $X$ is

$$U_{i,X}=q_i+(q_X-q_i)t_X. \tag{1}$$

Here, $q_i$ denotes consumer $i$'s expectation of ethical quality. $q_X$ is the true value of supplier X's ethical quality. Suppliers disclose their supply chain information with a certain transparency level ($t_X$). The more information a supplier discloses, the closer to the true value the estimate becomes. Consumer $i$ chooses product X (Y) when $U_{i,X}>U_{i,Y}$ ($U_{i,X}<U_{i,Y}$). We also assume that when $U_{i,X}=U_{i,Y}$, consumers choose a product randomly. Table 1 shows the market demand for each product ($D_X$,$D_Y$) under the assumption that $q_i$ is uniformly distributed between 0 and 1.

Based on the market demand in Table 1, the profit function of a supplier is defined as

$$\pi_X=D_X\cdot(1-c_q q_X)-\frac{1}{2}c_t t_X^2, \tag{2}$$

where $c_q$ and $c_t$ denote the cost parameters of ethical production and supply chain transparency, respectively. These cost parameters are

**TABLE 1** Market demand for each product

| | $t_X>t_Y$ | $t_X<t_Y$ | $t_X=t_Y$ |
|---|---|---|---|
| $t_Xq_X>t_Yq_Y$ | $(A, 1-A)$ | $(1, 0)$ | $(1, 0)$ |
| $t_Xq_X<t_Yq_Y$ | $(0, 1)$ | $(A, 1-A)$ | $(0, 1)$ |
| $t_Xq_X=t_Yq_Y$ | $(0, 1)$ | $(1, 0)$ | $(0.5,0.5)$ |

defined between 0 and 1 ($c_q$, $c_t \in (0, 1)$). Since we normalize the market price to 1, $(1-c_q q_X)$ represents the marginal profit. The second term is the R&D costs incurred owing to firm *i*'s supply chain transparency decision. The quadratic form of R&D costs is widely used and specified in various studies, including those of Aghion et al. (2001), Baik and Kim (2020), Bourreau and Dogan (2010), d'Aspremont and Jacquemin (1988), Haaland and Kind (2008), Ishida et al. (2011), Lin and Zhou (2013), Milliou and Pavlou (2013), and Tishler and Milstein (2009). In this study, this term more specifically implies that the cost of supply chain transparency for each good should not exceed the marginal cost. Otherwise, firms would not disclose their supply chain information.

## 2.2 | Results

The ethical quality and supply chain transparency levels have two values (high and low). We assume that the high value is 0.9 and the low value is 0.1. Table 2 presents the payoff depending on the ethical quality and supply chain transparency levels of the two suppliers. The table indicates that if the two suppliers are different types, the more ethical supplier monopolizes the market regardless of its actions. However, when they are the same type, higher supply chain transparency increases a supplier's market share.

Both the suppliers know their own ethical quality levels but not the other's ethical quality level. They believe that the rival's ethical quality has a high value with probability *p*. A supplier chooses the supply chain transparency level based on the ethical quality level. Thus, a supplier has four strategies: {*hh*, *hl*, *lh*, *ll*}. *hh* denotes that a supplier chooses the high supply chain transparency level regardless of the ethical quality level. *hl* denotes that a supplier chooses the high supply chain transparency level when the ethical quality level is high and the low supply chain transparency level when the ethical quality level is low. The other strategies are interpreted in the same way. The suppliers choose a strategy to maximize their expected profit. Table 3 shows the pure strategy Nash equilibria depending on the parameters. The cost parameter of ethical quality $c_q = 0.1$.

A pure strategy Nash equilibrium exists when $p \le c_t$. In the equilibrium, both the suppliers choose *lh* or *ll* depending on the parameter conditions. Hence, when the pure strategy Nash equilibrium exists, the suppliers disclose less supply chain information when they are lemon firms. The degree to which peach firms disclose supply chain information varies according to the parameter conditions. As shown in Table 3, a lemon firm selects a high supply chain transparency level when $p + c_t < 1$, but a low supply chain transparency level when $p + c_t \ge 1$. Therefore, lemon firms tend to choose a low supply chain transparency level when *p* and $c_t$ are higher. A similar trend is expected for peach firms, but it is difficult to confirm this using pure strategy Nash equilibria. Therefore, we calculate the mixed strategy Nash equilibria for the parameter conditions for which no pure strategy Nash equilibria exist. Table 4 shows the mixed strategy Nash equilibria when $c_t$ or *p* is fixed.

**TABLE 2** Payoff matrix

| | | Supplier X | | | |
|---|---|---|---|---|---|
| | | ***Hh*** | ***Hl*** | ***Lh*** | ***Ll*** |
| Supplier Y | *Hh* | (0.5,0.5) | (0.1,0.9) | (0,1) | (0,1) |
| | *Hl* | (0.9,0.1) | (0.5,0.5) | (0,1) | (0,1) |
| | *Lh* | (1,0) | (1,0) | (0.5,0.5) | (0.1,0.9) |
| | *Ll* | (1,0) | (1,0) | (0.9,0.1) | (0.5,0.5) |

*Note*: This table shows the payoffs of the suppliers depending on their ethical quality and supply chain transparency levels. The capital letters (*H* and *L*) indicate the ethical quality level, and the small letters (*h* and *l*) indicate the supply chain transparency level.

**TABLE 3** Pure strategy Nash equilibria

| *p* / $c_t$ | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|---|---|---|---|---|---|---|---|---|---|
| 0.1 | *lh* | | | | | | | | |
| 0.2 | *lh* | *lh* | | | | | | | |
| 0.3 | *lh* | *lh* | *lh* | | | | | | |
| 0.4 | *lh* | *lh* | *lh* | *lh* | | | | | |
| 0.5 | *lh* | *lh* | *lh* | *lh* | *ll* | | | | |
| 0.6 | *lh* | *lh* | *lh* | *ll* | *ll* | *ll* | | | |
| 0.7 | *lh* | *lh* | *ll* | *ll* | *ll* | *ll* | *ll* | | |
| 0.8 | *lh* | *ll* | *ll* | *ll* | *ll* | *ll* | *ll* | *ll* | |
| 0.9 | *ll* | *ll* | *ll* | *ll* | *ll* | *ll* | *ll* | *ll* | *ll* |

*Note*: This table shows the pure strategy Nash equilibrium. *p* denotes the probability that a supplier is ethical. $c_t$ denotes the cost parameter of the transparent supply chain. Under the *lh* strategy, a supplier chooses the low supply chain transparency level when the supply chain is ethical and chooses the high supply chain transparency level when the supply chain is unethical. Under the *ll* strategy, a supplier chooses a low supply chain transparency level regardless of the ethical quality level. Since the two suppliers are symmetric, the table shows only one supplier's strategies.

In the mixed strategy Nash equilibria, *ll* is generally not selected. As shown in Panel A of Table 4, when $c_t$ is fixed, as *p* increases, the probability that a supplier selects *hh* or *lh* decreases, while the probability of selecting *hl* increases. As shown in Panel B of Table 4, when *p* is fixed, as $c_t$ increases, the probability that a supplier selects *hh* or *lh* increases, while the probability of selecting *lh* decreases. This pattern is more clearly shown when the optimal strategy is organized by the type of supplier. Table 5 reorganizes Table 4 according to the supplier's type.

The results in Tables 3 to 5 can be summarized as follows. First, as the probability that the rival is a peach firm increases, the peach firm raises its supply chain transparency level, whereas the lemon firm lowers its supply chain transparency level. As consumers' demand for ethical production increases, the likelihood of ethical production companies existing also increases. Thus, the supply chain transparency level can be a signal of the ethical quality of a supplier. If the supply chain transparency level becomes a clear

**TABLE 4** Mixed strategy Nash equilibria

| Panel A. Mixed strategy Nash equilibria when $c_t = 0.1$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *p* | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| *hh* | 0 | 0.86 | 0.76 | 0.67 | 0.52 | 0.37 | 0.24 | 0.16 | 0.12 |
| *hl* | 0 | 0.02 | 0.09 | 0.21 | 0.37 | 0.55 | 0.7 | 0.81 | 0.87 |
| *lh* | 1 | 0.12 | 0.12 | 0.12 | 0.11 | 0.08 | 0.06 | 0.03 | 0.01 |
| *ll* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Panel B. Mixed strategy Nash equilibria when $p = 0.9$ | | | | | | | | | |
| $c_t$ | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| *hh* | 0.12 | 0.23 | 0.33 | 0.44 | 0.55 | 0.66 | 0.76 | 0 | 0 |
| *hl* | 0.87 | 0.75 | 0.63 | 0.5 | 0.38 | 0.26 | 0.14 | 0.1 | 0 |
| *lh* | 0.01 | 0.03 | 0.04 | 0.05 | 0.07 | 0.08 | 0.09 | 0.02 | 0 |
| *ll* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.88 | 1 |

*Note*: This table shows the mixed strategy Nash equilibria. *hh* denotes that a supplier chooses the high supply chain transparency level regardless of the ethical quality level. *hl* denotes that a supplier chooses the high supply chain transparency level when the ethical quality level is high and the low supply chain transparency level when the ethical quality level is low. The other strategies are interpreted in the same way. Each cell indicates the probability that a supplier chooses a strategy. Since the two suppliers are symmetric, the table shows only one supplier's strategies.

**TABLE 5** Optimal strategy by the ethical quality level

| Panel A. Optimal strategy by the ethical quality level when $c_t = 0.1$ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *p* | | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| *H* | *h* | 0 | 0.88 | 0.85 | 0.88 | 0.89 | 0.92 | 0.94 | 0.97 | 0.99 |
| | *l* | 1 | 0.12 | 0.12 | 0.12 | 0.11 | 0.08 | 0.06 | 0.03 | 0.01 |
| *L* | *h* | 1 | 0.98 | 0.88 | 0.79 | 0.63 | 0.45 | 0.3 | 0.19 | 0.13 |
| | *l* | 0 | 0.02 | 0.09 | 0.21 | 0.37 | 0.55 | 0.7 | 0.81 | 0.87 |
| Panel B. Optimal strategy by the ethical quality level when $p = 0.9$ | | | | | | | | | | |
| $c_t$ | | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| *H* | *h* | 0.99 | 0.98 | 0.96 | 0.94 | 0.93 | 0.92 | 0.9 | 0.1 | 0 |
| | *l* | 0.01 | 0.03 | 0.04 | 0.05 | 0.07 | 0.08 | 0.09 | 0.9 | 1 |
| *L* | *h* | 0.13 | 0.26 | 0.37 | 0.49 | 0.62 | 0.74 | 0.85 | 0.02 | 0 |
| | *l* | 0.87 | 0.75 | 0.63 | 0.5 | 0.38 | 0.26 | 0.14 | 0.98 | 1 |

*Note*: This table shows the optimal strategy depending on the ethical quality level. The capital letters (*H* and *L*) indicate the ethical quality level and the small letters (*h* and *l*) indicate the supply chain transparency level. The other strategies are interpreted in the same way. Each cell indicates the probability that a supplier chooses a strategy. Since the two suppliers are symmetric, the table shows only one supplier's strategy.

signal of ethical production, demand for lemon firms' products decreases, turning lemon firms into peach firms. This can increase the overall utility of society.

Second, efficient technology for disclosing supply chain information makes peach firms more transparent but lemon firms less transparent. This result implies that efficient information technology makes the supply chain transparency level a clearer signal of ethical production. Therefore, information technology that can efficiently build a transparent supply chain can help increase the use of ethical production processes. Recent studies argue that blockchain technology is considered theoretically and practically efficient for supply chain transparency (Bai & Sarkis, 2020; Chod et al., 2020; Unnevehr, 2022). Therefore, we examine whether blockchain technology is an alternative technology to foster supply chain transparency in Section 3. We summarize real-time transparency, a feature of blockchain technology, and review cases of fostering supply chain transparency using blockchain technology.

## 3 | BLOCKCHAIN TECHNOLOGY FOR A TRANSPARENT SUPPLY CHAIN

### 3.1 | Blockchain technology and real-time transparency

To provide supply chain transparency, a firm must disclose its ledger. Systems for disclosing ledgers can be categorized as centralized and distributed ledger systems depending on who creates and manages the ledger. In a centralized ledger system, a single entity with the appropriate authority manages the supply chain. This entity may be a firm within the supply chain or an external agency. Centralized ledgers such as banking systems are widely used without issue. Trust makes such systems possible, and users pay trust fees to these organizations, which then provide services and store, secure, and utilize data. However, third-party centralized ledger systems may charge excessive management and brokerage fees, and some incur substantial security maintenance costs. A process for delivering the data to a centralized manager is also necessary to operate a centralized system. Including a large number of intermediate processes can increase the time and costs incurred, thereby reducing efficiency. Moreover, if a supply chain uses a centralized database, hackers need only target that one database. Thus, even when serious efforts are made to maintain security, the risk remains because hackers' targets are not distributed. If hackers attack the central database, all the center's data will be breached. Additionally, the ledger's managers may commit fraud.

Real-time transparency, which makes the distributed ledger transparent to users in real-time, is one of the main features of blockchain technology (Ko et al., 2018). Blockchain's distributed ledger is transparent because data are uploaded to a ledger shared among participants. Furthermore, these data are impracticable based on the time-stamping feature of blockchain technology. The most famous example is Bitcoin, which renders the concept of a bank's central ledger as a distributed ledger, allowing participants in the distributed ledger to verify each other's virtual accounts. The term "real-time transparency" describes the real-time availability of the information uploaded to the blockchain. Most studies use the term "transparency" rather than "real-time transparency," although Yermack (2017) defined the real-time disclosure of managers' equity trades as real-time transparency.

In a broad sense, blockchain technologies can be grouped into four types according to the combination of writing and reading authorizations on the digital distributed ledger (Drescher, 2017; Mougayar, 2016). A "permissionless" blockchain allows all users (nodes) to write new information on a digital distributed ledger. Conversely, a "permissioned" blockchain allows only selected users (nodes) to write on the digital distributed ledger. A "disclosed" blockchain allows all users to access information on a digital distributed ledger, whereas a "closed" blockchain allows only selected users to access that information.

Lai and Chuen (2018) developed instructions for commercial uses depending on the type of blockchain technology. Zheng et al. (2018) compared blockchain technology types across consensus algorithms such as the proof of work, proof of stake, and practical Byzantine fault tolerance algorithms. They suggested that general blockchain technology can be applied in various industries such as finance, the IoT, and public and social services. However, while they contributed to the literature by providing a basic identification of blockchain types, they did not explain which types can be applied to which industries. Dinh et al. (2017) attempted to evaluate the usefulness of permissioned blockchain technology according to a new standard. They examined the consensus, data model, execution, and applications of one blockchain technology, namely, BLOCKBENCH.

Studies of the applications of blockchain types are crucial for practitioners. For example, Morkunas et al. (2019) discussed the various applications of types of blockchain technologies to support general managers and executives. Practitioners often require functions that are not provided by a single technology. For example, Walmart tackles food safety in the supply chain using blockchain technology (Kamath, 2018). Hence, the company may want to disclose information about its goods to consumers worldwide to demonstrate and advertise the safety of its vegetables. Disclosing such product information to consumers may also encourage suppliers to improve their product quality. However, the Hyperledger Fabric, the blockchain platform selected by Walmart, does not proffer these advantages because it is a closed, permissioned blockchain platform (i.e., it is not disclosed publicly). Such challenges make it possible for a hybrid blockchain platform to pioneer a niche market. A hybrid blockchain platform combines an open, permissionless blockchain with a closed, permissioned blockchain in a single frame; in other words, the ledger is distributed publicly, whereas the data are restricted to a firm. Thus, a firm can disclose the quality and origin of its goods to consumers while limiting their access to sensitive data such as financial transactions with suppliers.

Lin, Haldenby, et al. (2019) developed a firm-level hybrid blockchain architecture to simplify businesses with multiple lines and business units along the chain from suppliers to consumers. They even incorporate the concept of smart contracts into the architecture (although they do not explicitly use that term) to extend the architecture's usage to e-commerce. Using this architecture, the cost of proving that suppliers, goods, and payments are appropriate should decrease for suppliers, firms, and consumers. In addition, blockchain technology enables automated management through the digitalized ledger, which is expected to improve efficiency when RFID and IoT are used as recording devices. Smart contract technology, which automatically executes contracts based on the records in a blockchain, can also increase efficiency. Although using these technologies to reduce costs may still be controversial from a technical standpoint, blockchain has great potential.

As blockchain technology's potential to create a reliable and transparent supply chain attracts research attention, many studies are proposing supply chain management using such technology. For example, the Chinese agricultural market, which faces issues with fraud, could combine blockchain and RFID technology to supply high-quality agricultural products (Tian, 2016). Tse et al. (2017) suggested a method for improving food quality using the transparency provided by blockchain technology. In addition, studies argue that the quality of composite materials can be improved by increasing supply chain transparency using blockchain technology (Mondragon et al., 2018). Tian (2017) designed a food supply chain using BigchainDB, which is proposed by McConaghy et al. (2016). Tian (2017) re-emphasized the real-time access to information afforded to warehouse management, cold chain distribution, and the retailer. Andoni et al. (2019) explained that blockchain technology may resolve imbalances in electricity production by supplying transparent energy generation and consumption records to energy wholesalers in real time. Benchoufi et al. (2017) devised a protocol for providing transparent and traceable consent for clinical trials in real time. Montecchi et al. (2019) described a blockchain platform-based supply chain that can be applied to various industries. The principal function of this architecture is to provide trustable origins of goods in real time using the blockchain's transparent distributed ledger.

### 3.2 | Case Study 1: Food safety and fair-trade coffee

In the food industry, supply chain transparency is a traditional agri-food supply chain issue that is particularly important for mitigating safety problems (Ahumada & Villalobos, 2009). Unlike other types of products, food quality is directly related to public health. Consumers also place high expectations on safe food supply chains. Therefore, studies of the food industry examine how to share information on food quality, including soil quality, storage conditions, and weather patterns (Bhat et al., 2021; Tirado et al., 2010). Many studies aim to implement a safe and efficient food supply chain by applying a blockchain-based traceability system (Tharatipyakul & Pongnumkul, 2021). Blockchain is a promising technology for the traceability of food safety because of its irreversible time stamp, smart contracts, and consensus algorithms (Lin, Wang, et al., 2019). Blockchain and smart contracts are run as automated systems to ensure food supply chain transparency (Casino et al., 2021). In the food supply chain, blockchain technology is combined with IoT technology to form an effective food traceability system that can make it easy for consumers to acquire transaction information (Feng et al., 2020; Tsang et al., 2021).

However, consumers are beginning to demand that supply chain information be disclosed from a viewpoint other than safety. Some are emphasizing ethical production in the food supply chain, for instance (Schouteten et al., 2021). Fair-trade coffee is a representative case of ethical production in the food industry. As demand for coffee has increased in recent times, the coffee market has begun to grow rapidly. However, as coffee supplies increase in response, coffee growers are paying less than coffee retailers. The fair-trade coffee movement has thus emerged since the 1960s to reduce the price gap between coffee retailers and coffee growers. As such, consumers' interest in fair-trade coffee has risen (Omidvar & Giannakas, 2015).

Although coffee is one of the most widely consumed and traded commodities globally, the value chain of coffee is considered to be opaque (Miatton & Amado, 2020). In particular, since coffee is produced in developing countries and consumed mainly in developed countries, unfair trade is highly likely to take place. To solve the opaqueness of the coffee value chain, some coffee firms, including Starbucks, have adopted a blockchain technology-based transparent supply chain to show their fairness to consumers (Thiruchelvam et al., 2018). Using fair-trade labels can increase consumption. Bürgin and Wilken (2021) argued that the high-cost problem of fair trade can be solved by raising consumers' awareness of the benefits of fair trade. Blockchain technology has the potential to enhance the effectiveness of eco-labeling. Because consumers can track the flow of coffee production using the blockchain-based traceability system, they can monitor coffee firms' deviation from ethical practices (Garaus & Treiblmaier, 2021).

### 3.3 | Case Study 2: Battery supply chain of the Responsible Sourcing Blockchain Network (RSBN)

The Ford Motor Company, Huayou Cobalt, LG Chem, RCS Global, and IBM, members of the RSBN, are devising ways to extend the supply chain transparency of lithium-ion batteries to automobile manufacturing.[2] This involves transparent battery production by LG Chem on an IBM blockchain platform. The production process starts with cobalt production, which is the main component of lithium-ion batteries, by Huayou Cobalt in the Democratic Republic of Congo (DRC) and ends at the Ford Motor Company. Using the immutable and real-time data uploading provided by a blockchain platform, the firms in this supply chain are expected to not only improve product quality (e.g., address issues of ethics and sustainability during production) but also reduce costs. The RSBN plans to extend the supervision of the battery component supply chain to tantalum, tin, tungsten, and gold for original equipment manufacturers across the electronics, aerospace, and defense industries.

The quality of RSBN members' production can improve by using real-time transparency, as unethical cobalt production can be supervised and fixed on the blockchain platform. Cobalt is becoming one of the most widely used metals worldwide because of the increase in demand for products (e.g., electric cars) that use it as the main component (batteries in this case). More than half of the world's cobalt production occurs in the DRC. Exposure to excess cobalt in the natural environment can cause cardiomyopathy, vision/hearing impairments, and many other diseases and is highly fatal (Paustenbach et al., 2013). However, child labor is intensively used in the cobalt industry. This kind of unethical approach leads to the production of low-quality batteries and cars. First, unethical production itself lowers the quality of goods because it is closely related to decreases in consumer demand (Helms & Hutchins, 1992). Second, ethical production improves product quality and helps create sustainable businesses in the long run (Maguad & Krone, 2009). Indeed, Nkulu et al. (2018) argued that the cobalt industry is unsustainable owing to its adverse effects on worker health and the environment.

The RSBN was established to apply blockchain technology to improve the origin of the battery components used in automobile production and, ultimately, product quality across the supply chain. Furthermore, it is expected to lower costs by skipping third-party auditing because immutable and real-time transparent blockchain data can be used to provide compliance information. Cobalt production is expected to be easily subordinated to internationally ratified responsibility compliance through this process.

The RSBN is aiming to expand this blockchain platform throughout the industry, supported by the quality improvements and cost savings provided by real-time transparency. However, firms and industries must have the incentive to deploy blockchain technology. For instance, although most studies consider real-time transparency to be a benefit of blockchain technology, companies are not always willing to provide real-time transparency. In practice, companies will only adopt blockchain technology if they have the incentive to do so. Importantly, firms must identify the incentives associated with adopting technology for it to be widely implemented. Adoption may be deterred by the possibility of firms' unfair use of information asymmetry to earn improper profits and the low cost of production for low-quality goods. For instance, consumers are likely to incorrectly judge the quality of goods if the product supply chain is insufficiently transparent. They may overestimate or underestimate such quality. Additionally, firms have the incentive to produce low-quality goods at low cost to benefit from information asymmetry. Conversely, even if a firm produces high-quality goods, it will not implement a blockchain platform unless the benefits from doing so are greater than the implementation costs. Thus, the benefits of real-time transparency must be greater than the losses from correcting information asymmetry for a firm to implement blockchain technology.

Specifically, a lemon supplier (i.e., a supplier of low-quality goods) may be reluctant to adopt blockchain technology if the market overestimates the quality of its goods in an opaque supply chain. In that case, mitigating information asymmetry through real-time transparency would reduce that firm's profits. However, it could benefit from implementing blockchain technology if the cost savings and improved competition caused by the increased product quality exceeded the benefits of maintaining information asymmetry. Conversely, peach suppliers may improve their competitiveness by publishing information about their goods if the supply chain is opaque. However, they may lack the incentive to implement blockchain technology if the original supply chain is sufficiently transparent because the additional benefits from the technology may be below its implementation costs. Thus, firms' preferences for enhancing and adjusting the degree of supply chain transparency depend on the situation.

## 4 | CONCLUSION

In this study, we examine firms' supply chain transparency decisions. Supply chain transparency can raise a firm's profits by increasing consumers' preferences for its products. However, when a firm releases its supply chain information, it may also be criticized by consumers. In particular, as ethical consumerism is increasing consumers' ethical standards, supply chain transparency can be risky for firms. We analyzed how the degree of supply chain transparency varies by firm type. We confirmed that peach firms raise their supply chain transparency level and lemon firms lower their supply chain transparency level, as the probability that the rival is a peach firm and the efficiency of technology for supply chain transparency is higher. This implies that as both consumers' demand for ethical production and R&D efficiency for supply chain transparency are increasing, the supply chain transparency level can be a signal of the supplier's ethical quality level. Because blockchain technology can improve the efficiency of R&D, we can expect consumers to distinguish ethical suppliers through their level of supply chain transparency.

We suggest using blockchain technology to foster supply chain transparency. Many studies and companies propose using blockchain to manage the supply chain. We describe several cases in the food and automobile battery supply chains as representative examples of blockchain applications. This study analyzes companies' decision making on supply chain transparency according to company type. It has practical implications in that it proposes using blockchain technology to foster supply chain transparency and describes case studies. In future work, empirical analyses of supply chain transparency could provide useful implications.


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## DATA AVAILABILITY STATEMENT

n/a; Theoretical paper


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## ENDNOTES

[1] We use the term "lemon" to describe low-quality goods and "peach" to describe high-quality goods, following the fundamental study of Akerlof (1970). However, as we explain in the Introduction, the terms "low quality" and "high quality" describe not only the true quality of the goods but also all the components that affect consumer sentiment, including unethical and unsustainable manufacturing processes.

[2] Dickinson, A. (2020). Blockchain and sustainability through responsible sourcing. IBM Supply Chain and Blockchain Blog (https://www.ibm.com/blogs/blockchain/2020/12/blockchain-and-sustainability-through-responsible-sourcing/).


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