

Article

Blockchain Technology and Manufacturing Industry: Real-Time Transparency and Cost Savings

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Abstract: Blockchain technology has been recommended for the sustainability in the manufacturing industry, owing to its benefits in terms of real-time transparency and cost savings. To verify this, we first examine how firms can employ distributed ledger technology by adopting blockchain technology to achieve real-time transparency and cost savings. We also review the current blockchain technology applications in the financial industry and supply chains to explain this technology's mechanisms for enabling real-time transparency and cost savings in the manufacturing industry. Finally, we theoretically compare the profits of manufacturing firms in two managerial delegation games under a duopoly situation. This theoretical model suggests that the real-time transparency and cost savings secured by blockchain technology improve the profitability and competitiveness of manufacturing firms, which, in turn, assure the sustainability in the manufacturing industry.

Keywords: blockchain; cost saving; distributed ledger technology; manufacturing industry; real-time transparency; sustainability

JEL Classification: D23, O14, O31, O33

1. Introduction

Large banks have not been able to (or, perhaps, have not) respond to the rapid Internet developments since the 1990s. Mougayar (2016) [1] states that bankers do not deny that large banks are losing profits to Internet-adapted financial companies, such as Paypal and Apple Pay. Currently, however, banks are facing another challenge: blockchain technology. This revolution in financial technology (i.e., Fintech) affects nearly all industries, not just banks and financial institutions. Nakamoto (2008) [2] was the first to devise the concept of blockchain technology, which is well known as distributed ledger technology (DLT). DLT differs from traditional ledger systems in that the distributed ledger is shared by all participants in the system. Blockchain technology is attractive to multiple industries, including the manufacturing industry, because it offers real-time transparency and reduced firm costs (Mougayar, 2016 [1]; Drescher, 2017 [3]). The distributed ledger system achieved through blockchain technology makes these advantages possible.

Since the proposal of this revolutionary architecture, market practitioners and experts have studied and implemented numerous applications of blockchain technology, starting with Bitcoin, the first cryptocurrency. However, Bitcoin is merely one example of the applications of blockchain technology; meanwhile, blockchain technology is the point we should focus on (Swanson, 2013 [4]). Blockchain technology has been increasingly applied in several other fields. The benefits of blockchain technology may lead to a change in the industrial hierarchy. Firms that effectively introduce blockchain technology are more likely to achieve higher profits than those that do not, primarily because of its

benefits in terms of real-time transparency and cost reductions (Mougayar, 2016 [1]; Drescher, 2017 [3]; Caytas, 2016 [5]; De Filippi, 2016 [6]; Pilkington, 2016 [7]; Underwood, 2016 [8]).

Given this environment, the main purpose of this study is to demonstrate the mechanism by which real-time transparency and cost savings induce manufacturing firms to introduce blockchain technology, which subsequently improves the firms' sustainability. We assume that the ownership and management of corporations are separated, as in Basu (1995) [9], Fershtman (1985) [10], Fershtman and Judd (1987) [11], and Sklivas (1987) [12], which can generate a time lag (i.e., delay) between an owner's decision and the actual production process. The real-time transparency offered by blockchain technology reduces this time gap, enabling owners to make preemptive output decisions.

We examine two situations in which two competing firms engage in a managerial delegation game under a duopoly situation. First, we calculate the profits and compensations of the owners and managers of a manufacturing firm that can be classified as a small and medium-sized enterprise (SME) and that competes with a market-dominating manufacturing firm in a managerial delegation game situation. We initially assume that neither firm has blockchain technology. After the manufacturing SME adopts blockchain technology, its profit changes, and we compare the profit of the SME before and after implementing blockchain technology. In the next section, we similarly examine two fairly competitive market-dominating firms in a managerial delegation game. The results show that in the case of an SME versus a market-dominating firm, the SME's profit is greater after implementing blockchain technology because of the additional profit from real-time transparency and cost savings. The model also briefly illustrates that the profit of a manufacturing firm with blockchain technology can exceed that of its competitor owing to real-time transparency. We find similar results for the game in which two market-dominating firms compete. Therefore, the enhanced real-time transparency and cost savings of blockchain technology make manufacturing firms more advantageous and sustainable.

This paper is organized as follows. Section 2 briefly presents prior studies on blockchain technology and the background of this study. Section 3 explains the need for blockchain technology for the integrity of DLT and discusses the real-time transparency and cost savings achieved through blockchain technology. We also describe the current researches and applications of blockchain technology in the financial industry and supply chains, which consequentially affect manufacturing firms. In the beginning of Section 4, we explain ways to reduce costs in manufacturing firms using blockchain technology, considering real-time transparency. Then, we explain the additional profits provided by blockchain technology through real-time transparency and cost savings by comparing the profit of a manufacturing firm using blockchain technology with its profit would have obtained had they not used the blockchain technology, under two managerial delegation games in a duopoly situation. Additionally, we briefly note the effects of real-time transparency. The manufacturing firms with blockchain technology earn higher profits than their opponents do. Section 5 discusses whether manufacturing firms are better off after adopting blockchain technology, the mechanism by which real-time transparency and cost savings secure the sustainability of manufacturing firms, and the limitations of blockchain technology. Finally, we briefly conclude this paper at the end of Section 5.

2. Literature Review

Nakamoto's (2008) [2] research, which introduced an algorithm for blockchain technology, was followed by many studies on the technology. Mougayar's (2016) [1] and Drescher's (2017) [3] books provide introductory explanations of the algorithm and the current state of blockchain technology for readers without advanced knowledge of computers. Mougayar's (2016) [1] book, *The Business Blockchain: Promise, Practice, and Application of the Next Internet Technology*, discusses the potential use of blockchain technology in businesses, and Drescher (2017) [3] clarifies the basic procedures through which blockchain technology works. In addition, Kossow and Dykes (2018) [13] and Iansiti and Lakhani (2017) [14] offer a well-organized discussion of the recent state of blockchain technology, its various applications, and its limitations. These works provide substantial insights into blockchain technology.

Catalini and Gans (2016) [15] review blockchain technology's mechanism for enabling cost savings. They provide more specificity around the vague arguments for blockchain technology's cost savings by dividing the cost reduction effects of blockchain technology into two categories: verification costs and networking costs. Yermack (2017) [16] investigates the potential effects of blockchain technology on corporate governance. He suggests that investors (i.e., shareholders) can increase their profits through the improved liquidity and lower costs achieved via blockchain technology. Moreover, the real-time transparency of blockchain technology allows investors to more easily supervise managers, and markets can form more efficient prices, as information asymmetries among managers, investors, and other market participants are resolved.

Ryan and Donohue (2017) [17] describe blockchain technology's uses for trading securities, discuss the limitations of blockchain technology applications and suggest guidance for corporate lawyers assisting corporations that are willing to transact securities over a blockchain platform. Walker and Venables (2017) [18] devise a specific application of blockchain technology to securities exchange, which they call SETLcoin, and Hallam et al. (2018) [19] design a network payment system for securities settlement using blockchain technology.

Tanner and Valtanen (2017) [20] explain the applicability and usefulness of blockchain technology in various fields of manufacturing industry. Abeyratne and Monfared (2016) [21] also suggest the applications of blockchain technology to supply chains in the manufacturing industry. They describe the positive effects of blockchain technology on the transparency of a supply chain and the quality of products. Extending this discussion, Mondragon, Mondragon, and Coronado (2018) [22] specifically examine the trade of composite materials in the manufacturing industry using a blockchain platform, emphasizing that the quality of products can be secured through blockchain technology. Tian (2016) [23] designs a method of combining blockchain technology with radio-frequency identification (RFID) to improve the quality of agri-food, focusing on Chinese agri-food markets, which has a complicated and often fraudulent supply chain system. Korpela, Hallikas, and Dahlberg (2017) [24] also discuss about the digitalization of supply chain system through blockchain technology.

Based on the studies of Mougayar (2016) [1] and Yermack (2017) [16], we elicit the logic of the effects of blockchain technology on the sustainability of manufacturing firms. Mougayar (2016) [1] suggests that large banks should actively employ blockchain technology in their businesses, supporting the active implementation of blockchain technology to avoid ceding profits to start-up financial companies. Yermack (2017) [16] argues that blockchain technology affects corporate governance, allowing shareholders (owners) to more easily monitor managers. Based on these two lines of reasoning, we evaluate how manufacturing firms adopt the blockchain technology under managerial delegation game situations. Through the framework of the delegation games, we propose that the sustainability of firms in the manufacturing industry is ensured by real-time transparency and reduced costs obtained by blockchain technology.

3. The Effects of Blockchain Technology and Industrial Applications

3.1. Distributed System Attained by Blockchain Technology and Real-Time Transparency and Cost Savings

A distributed system is made up of many single nodes (computers) working together. Each node is indirectly connected, and no single node is directly connected to all other nodes. By contrast, in a centralized system, all nodes are directly connected to a single central node. Distributed systems are preferred to centralized systems because of their faster calculation, reduced maintenance costs, greater stability, and easier upgrades (Drescher, 2017 [3]).

The main challenge to maintaining the integrity of a distributed system is interruptions by malicious peers who try to manipulate the distributed system for their own profits. Malicious peers sometimes send virus files to other peers to tamper with transaction information (Duma, Shahmehri, and Caronni, 2005 [25]), threatening confidence in the distributed system. Thus, peers may leave the system, leading to the loss of the entire system's functionality, a situation similar to the

Byzantine Generals Problem (Lamport, Shostak, and Pease, 1982 [26]). This problem hinders the implementation of a useful distributed system. However, blockchain technology has a solution to this problem. Blockchain technology secures the integrity of a distributed system through a consensus algorithm, which elicits the benefit of real-time transparency. The consensus algorithm is the agreement of digital ledger users for the addition of blocks to the blockchain system (Swanson, 2015 [27]). A successfully structured consensus algorithm allows a blockchain system to remain a trusted transaction system. A malicious peer must manipulate this consensus algorithm to corrupt the system. However, manipulating the whole consensus algorithm is very costly because of the complexity of finding the nonce, which is an answer for hash values. Hash values are random digits of specific lengths that symbolize the transaction information. Once a blockchain system successfully structures a consensus system, the distributed system becomes dependable. Moreover, during the process of structuring a blockchain system, real-time transparency can be secured. When a new block with new transaction information is uploaded to the blockchain system, all participants can review the information through the shared digital ledger. Thus, users can check the current state of accounts, the quality of goods, and other information in real time while preventing attacks by malicious peers.

In addition, real-time transparency can minimize the need for trusted intermediaries to intervene. For example, when a firm exports goods to a counterparty abroad, an intermediary is needed to ensure that the firm holds sufficient goods or that the counterparty has enough funds. This need arises because these kinds of transactions generally occur sequentially; either one party sends the goods prior to payments or the counterparty pays before the goods are sent. However, if the counterparty's financial affairs utilize blockchain technology, the firm can check its counterparty's account, allowing it to send the goods with confidence. Conversely, the counterparty can pay first with confidence if the counterparty is provided with the firm's updated inventory information in the blockchain system. Blockchain technology can also solve this trust problem using a smart contract (Buterin, 2014 [28]; Cohn, West, and Parker, 2017 [29]; Wood, 2014 [30]). A smart contract can be enforced using an off-chain technology called a smart-oracle. A smart-oracle comprises data that are not saved in the blockchain but are uploaded to a real-life platform. The smart-oracle can be connected to the blockchain system. In the exporter example described above, the smart-oracle may be data from the importer country's custom clearance. A tamper-proof blockchain contract can be enacted when the exporter's goods successfully clear customs. Thus, as the exporter's goods clear customs in the importer's country, the exporter is automatically paid a certain amount from the counterparty's cryptocurrency account uploaded to the blockchain contract. Consequently, a trusted intermediary is less necessary, and intermediary costs fall.

3.2. *The Effects of Blockchain Technology in the Financial Industry on Manufacturing Firms*

Introducing blockchain technology to financial markets (Caytas, 2016 [5]), considering its potential for real-time transparency and cost reductions, is tempting to financial firms. However, these innovations are not limited to the financial industry. The application of blockchain technology to the financial industry can also affect manufacturing firms. The effects of blockchain technology in the financial industry can influence manufacturing firms' compensations through real-time transparency and cost savings.

3.2.1. Security Markets

Goldman Sachs, one of the most powerful global investment banks, is showing great interest in applying blockchain technology to its business. On October 2014, Goldman Sachs files a patent application titled "Cryptographic Currency for Securities Settlement", called SETLcoin, with the U.S. Patent & Trademark Office (USPTO), and on July 2017, the USPTO issues the patent to Goldman Sachs. SETLcoin enables the use of a blockchain platform for securities transactions. It provides a virtual wallet for each user. The user then trades financial assets using SETLcoin, which is saved in the virtual wallet (Walker and Venables, 2017 [18]).

NASDAQ also shows great interest in blockchain technology. Since 2015, it is in the process of developing a blockchain-based private equity exchange system in cooperation with Chain, a blockchain start-up company ("*NASDAQ launches enterprise-wide blockchain technology initiative*," <http://ir.nasdaq.com/news-releases/news-release-details/nasdaq-launches-enterprise-wide-blockchain-technology-initiative>). In 2016, NASDAQ announces the NASDAQ Linq Blockchain Ledger Technology, designed to allow private securities transactions to be conducted using blockchain technology ("*Building on the blockchain*," <https://business.nasdaq.com/marketinsite/2016/Building-on-the-Blockchain.html>). Since then, NASDAQ is engaging in many projects related to blockchain technology. On September 2017, NASDAQ and a leading Nordic corporate bank, SEB, announced a joint project for the development of a mutual fund trading platform using blockchain technology ("*SEB and NASDAQ to build blockchain for Swedish mutual fund market*," <https://business.nasdaq.com/mediacenter/pressreleases/1621844/seb-and-nasdaq-to-build-blockchain-for-swedish-mutual-fund-market>). The Swedish mutual fund market is influential, but its current platform for mutual fund transactions is relatively old, complicated, and costly ("*How blockchain will revolutionize Sweden's mutual fund industry*," <https://business.nasdaq.com/marketinsite/2018/MT/How-Blockchain-Will-Revolutionize-Swedens-Mutual-Fund-Industry.html>). These inefficient transactions are due to multiple intermediaries, hand workings, and no tracking system. Blockchain technology is envisaged as a mean to solve these problems through real-time transparency and time-stamps.

These applications of blockchain technology to securities trading platforms secure real-time transparency and reduce the surveillance costs on managers in manufacturing firms. Owners supervise managers because managers often trade financial assets held by their own firms to temporarily increase their firms' share price and exaggerate performances. With blockchain technology, the real-time transparency achieved through irreversible digital ledgers and the time-stamps allow owners to review managers' current and past financial trades with little effort, resulting in cost savings for manufacturing firms as the owners no longer require the costly surveillance party.

3.2.2. Remittance System

Another financial application of blockchain technology was developed by Ripple Labs, which is a leading blockchain company in the field of global payment systems since 2012 (Pilkington, 2016 [7]). Ripple Labs provides a platform for remittances using a blockchain system. It uses three different platforms: "xCurrent", "xRapid", and "xVia". Each platform has a unique function; xCurrent is used for bank-to-bank transactions, xRapid is used for transactions between payment providers and financial institutions, and xVia is used for transactions between corporations, payment providers, and banks and beneficiaries. Interestingly, xRapid uses XRP, the cryptocurrency of Ripple Labs, to complete transactions and, therefore, can benefit from XRP. XRP handles 1500 transactions per second (TPS), whereas Ethereum and Bitcoin can handle 15 TPS and 3–6 TPS, respectively. Ripple Labs' blockchain platform-based transactions are attractive owing to their instant settlement, low operational and liquidity costs, and traceable payments. These advantages lead Kotak Mahindra Bank in India to implement the xCurrent protocol to simplify its remittance procedures. India is among the countries with the most remittances, which reached US\$ 65 billion in 2017, according to The World Bank ("*Remittances to recover modestly after two years of decline*," <http://www.worldbank.org/en/news/press-release/2017/10/03/remittances-to-recover-modestly-after-two-years-of-decline>).

Applying blockchain technology to a remittance system lowers the commission fees on the trading and intermediate goods of manufacturing firms, leading to decrease in variable costs. For example, firms operated under blockchain technology can save commission fees on the remittances that occur during the transactions of intermediate goods by bypassing banks' complicated remittance systems.

3.3. The Effects of Blockchain Technology in Supply Chains on Manufacturing Firms

Applications of blockchain technology to supply chains are being actively developed. Blockchain technology can be adopted in the supply chains of various industries, such as the manufacturing industry and agri-foods (Abeyratne and Monfared, 2016 [21]; Mondragon, Mondragon, and Coronado, 2018 [22]; Tian, 2016 [23]). Firms seeking to apply blockchain technology to their supply chains expect to enhance their systems through two advantages. First, they can cut costs because no additional surveillance on the quality of goods is needed owing to the real-time transparency of blockchain technology. Second, the quality of goods can be guaranteed.

Supply Chains

Blockchain technology in supply chains works as follows. When the ownership of a product being processed is transferred from one party to another, the new owner becomes the only party who can update the product's status. When the new owner further processes the product, and updates the product status, this new information becomes a block and is uploaded to the shared ledger (blockchain). However, for this information to be uploaded to the shared ledger, the next recipient of the product must agree with the information. If the receiver agrees, then the correct product status is uploaded to the shared ledger. The recipient of the goods does not agree to the update if the data are inaccurate because they are directly related to his or her profits.

A blockchain system and RFID technology can be combined to support the agri-food industry's supply chain transparency (Tian, 2016 [23]). First, the RFID technology confirms data regarding the current state, such as process, warehouse, distribution, and so on, of a particular agri-food product. This information can be uploaded to the blockchain system instantly through a wireless network. RFID works in the similar way as a smart-oracle does. Blockchain technology's algorithmic irreversibility prevents tampering with the information. Therefore, anyone who needs accurate information about agri-food products can access the data in the shared ledger. For example, consumers or government departments can use this information to check the safety of agri-food products.

In practice, DLTs, such as IBM Fabric, R3 Corda, and Digital Asset Holding, are being used to enhance supply chains. However, blockchain technology-based DLTs enhance trust in transactions. If DLT technologies are implemented under a blockchain platform, they inspire even more confidence owing to the irreversible feature of blockchain technology. This feature implies that the information uploaded to the DLT under blockchain technology cannot be manipulated in the future. Moreover, by using cryptocurrency as a means of transaction, blockchain technology allows for faster transactions and reduces additional fees that may be incurred during transactions (Tanner and Valtanen, 2017 [20]).

Blockchain technology applied to a supply chain effectively reduces the verification costs of manufacturing firms and prevents distortions of the quality of goods through real-time transparency. Another application of blockchain technology in the manufacturing industry is found in supply chains of composite materials. Blockchain technology's characteristic of ownership transfer allows the provenance of materials to be traced, thereby reducing verification costs and providing an exact status of the quality of composite materials throughout the long supply chain. Components and structures made up of composite materials are generally utilized in the aerospace and medical industries (Mondragon, Mondragon, and Coronado, 2018 [22]). Thus, proof of the actual state and quality of the composite materials, which can be ensured by blockchain technology, is important for safety reasons.

4. Competition between Manufacturing Firms with and without Blockchain Technology: Effects of Real-Time Transparency and Cost Savings

In this section, we first explain the specific reasons for analyzing manufacturing firms and the means for achieving real-time transparency and cost savings in the manufacturing industry. Next, we analyze two managerial delegation games under a duopoly situation. Following Basu (1995) [9], the manufacturing firms in these games are assumed to have owners and managers. Initially, owners

employ a manager, which means that $(m_1, m_2) = (1, 1)$. For $i = 1$ and 2 , $m_i = 1$ indicates that firm i 's manager is employed, and $m_i = 0$ indicates that a manager is not employed. We first calculate the profit of an SME without blockchain technology that competes with a market-dominating firm. Then, we assume that the SME adopts blockchain technology and, as a result, obtains priority for production over the rival firms, similar with the Basu's (1995) [9] case of $(m_1, m_2) = (0, 1)$. We compare the profit in this case with the previous profit obtained without blockchain technology. The profit of the firm with blockchain technology is also briefly compared to that of its rival firm. Next, two market-dominating firms are examined in the same way. The results of this analysis show that as firms adopt blockchain technology to their businesses, their profits increase owing to the effects of real-time transparency and cost savings. For the delegation games, we ignore corner solutions for the simplicity. These owner-manager models are based on the owner-manager games of Basu (1995) [9], Fershtman (1985) [10], Fershtman and Judd (1987) [11], and Sklivas (1987) [12].

4.1. Real-Time Transparency and Cost Savings of Manufacturing Firms

We focus on manufacturing firms, because, as described in Section 3.2, applications of blockchain technology to the financial industry and supply chains considerably impact manufacturing industries. In particular, applications of blockchain technology to securities markets are being vigorously developed by large investment banks, such as JP Morgan and Goldman Sachs (Ryan and Donohue, 2017 [17]; Walker and Venables, 2017 [18]; Hallam et al., 2018 [19]). Moreover, NASDAQ is also developing a private equity exchange platform using blockchain, the NASDAQ Linq Blockchain Ledger Technology. Supply chains as composite material and agri-food supply chains have scope to employ blockchain technology as well. These applications are expected to have major impacts on the behaviors of owners and managers working in manufacturing firms because of real-time transparency and cost savings.

The effects of blockchain technology on the manufacturing industry primarily arise because of this technology's influence on financial transparency and manufacturing supply chains. Real-time financial transparency allows firms using blockchain technology to reduce verification and surveillance costs. Manufacturing firms implementing blockchain technology can structure confident relationships with their counterparts, thereby eliminating the cost of trust and reducing verification costs. Verification costs are incurred because of a lack of trust between traders (Catalini and Gans, 2016 [15]). For instance, when a manufacturing firm does business with intermediate goods suppliers, the suppliers must consider the potential of default and fraud by the manufacturing firm and require the manufacturing firm to prove that it has sufficient funds to pay for the transaction. Because of this lack of trust and the risk of default, an audit or intermediary is needed, and the manufacturing firm incurs verification costs. These costs can be estimated based on the income of the accounting industry, which is anticipated to surpass 156 billion US dollar in 2018 in the U.S. alone ("*Accounting industry in the U.S.—Statistics & Facts*," <https://www.statista.com/topics/2121/accounting-industry-in-the-us/>). The effective use of blockchain technology allows a manufacturing firm to provide its true financial status (real-time accounting) to the supplier, rendering verifications by an accounting firm unnecessary. Therefore, the manufacturing firm can save a significant amount of verification costs (Figure 1).

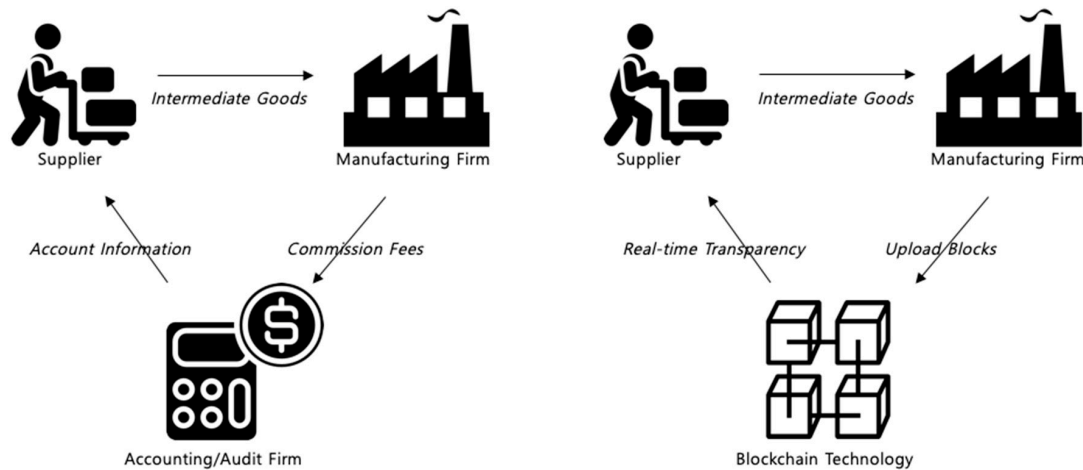


Figure 1. Elimination of a Manufacturing Firm's Verification Costs.

In addition, the real-time transparency of blockchain technology allows the owners of manufacturing firms to cut the surveillance costs on managers. A single shareholder (i.e., an owner) may experience difficulty steering a firm because the firm's shares are spread among many shareholders. When a firm has many owners, shareholders' interests generally do not coincide. Berle and Means (*"The Modern Corporation and Private Property"*) explain that the problem of diverse interests among shareholders is solved according to managers' preferences. As a result, manufacturing firms incur additional costs to supervise managers. However, these costs can be reduced through the real-time transparency of blockchain technology. In general, a firm's transparency is divided into two components, financial transparency and corporate governance transparency (Bushman, Piotroski, and Smith, 2004 [31]). However, a blockchain system can provide both financial (Pilkington, 2016 [7]; Underwood, 2016 [8]) and corporate governance transparency (Yermack, 2017 [16]). Thus, the actions of managers can be supervised in real time. As a result, intensive surveillance is no longer needed, lowering surveillance costs. For instance, an owner of a manufacturing firm can monitor the blockchain of a supply chain to observe whether a manager is maximizing profit. She can track the amount of intermediate goods that the manager purchases to estimate the quantity that the manager is planning to produce. Thus, the owner can reduce surveillance costs (Figure 2).

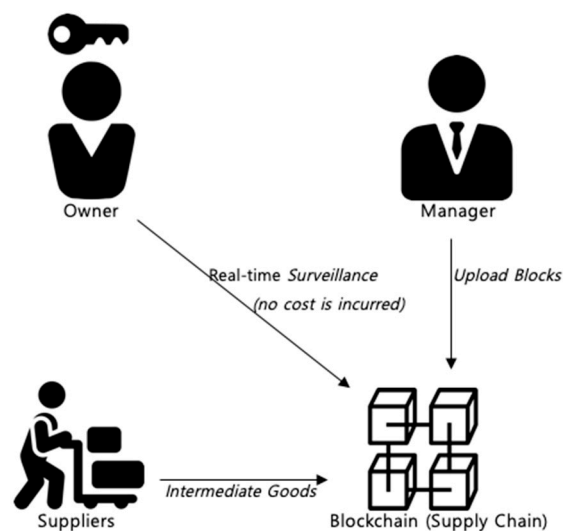


Figure 2. Surveillance Cost Savings in a Manufacturing Firm.

Networking costs can be saved among in-chain manufacturing firms, and the in-chain manufacturing firms with intermediate goods suppliers can develop a new market platform,

where in-chain firms refer to the firms within a blockchain system. This process may produce network effects that render in-chain manufacturing firms more competitive than off-chain manufacturing firms. According to Catalini and Gans (2016) [15], firms with blockchain technology can cut networking costs by bypassing intermediary intervention using blockchain technology participants' new transaction platforms. Extending this argument to the manufacturing industry, manufacturing firms with blockchain technology can develop a new market platform with intermediate goods suppliers and no intermediaries. This new market platform under a blockchain system achieves lower transaction costs by bypassing intermediaries and renders the manufacturing firms within the blockchain system more competitive than the off-chain manufacturing firms. Furthermore, the manufacturing firms in the blockchain system can achieve the benefits of network effects. The more that intermediate goods suppliers engage in the blockchain system, the more that the in-chain manufacturing firms benefit from the excess market information. Thus, the manufacturing firms and their submarkets form even tighter platforms under blockchain technology.

4.2. Competition between an SME Manufacturing Firm with Blockchain Technology and a Market-Dominating Manufacturing Firm without Blockchain Technology

The objective functions of firms are much disputed, but they are traditionally understood to maximize profits. However, modern corporations and stakeholders have two interest groups—owners and managers—resulting in disagreements regarding the aims of the groups. Amihud and Kamin (1979) [32], Baumol (1977) [33], Cyert and March (1963) [34], Leibenstein (1979) [35], Marris (1964) [36], Simon (1964) [37], Vickers (1985) [38], and Williamson (1964) [39] describe ways that firms can deviate from profit maximization; for example, firms often maximize total revenue instead of net profits.

Managers of a firm could prefer to maximize revenue, even if owners require to maximize profit, to reduce the risks of downturn of a profit performance in the next period or to exaggerate their resume. Nonetheless, managers of SMEs that consider blockchain technology can behave as owners prefer, that is, they can maximize profit, for two reasons. First, because the owners of SMEs recognize that they cannot compete on market shares, so they focus on maximizing profit within a given output capacity rather than maximizing revenue. More importantly, if a blockchain system is implemented, business owners can monitor managers in real time owing to the real-time transparency of the blockchain system. For example, as explained in Section 4.1, if intermediate goods are purchased through the blockchain system, the owners can estimate managers' planned output by monitoring the amount of intermediate goods purchased by the managers. Thus, when managers behave suspiciously, that is to maximize revenue, the owners can intercede. In contrast, the owners and managers of traditional large corporations are likely to maximize revenue for market domination (Sklivas, 1987 [12]).

The real-time transparency of blockchain technology reduces surveillance, remittance, verification, and networking costs, as explained in the previous sections. Because of these advantages, manufacturing firms can produce at smaller marginal costs when they incorporate blockchain technology. We first analyze the effect of real-time transparency by comparing the profits of a firm before implementing blockchain technology to those after applying blockchain technology. Then, we consider cost savings. Significant lump-sum costs may be required to introduce blockchain technology to a business. However, these lump-sum costs are independent of a firm's production decision making and, thus, do not affect the marginal cost of the firm. We consider these lump-sum costs and examine the necessary cost savings from blockchain technology to exceed the lump-sum costs of applying this technology, which could be incentives for manufacturing firms to adopt this technology.

We consider two firms competing against each other. Firm 1 is an SME manufacturing firm, and firm 2 is a market-dominating manufacturing firm. Neither firm 1 nor firm 2 employs blockchain technology initially. The game proceeds as follows. First, the owners, with perfect foresight regarding their managers, choose the optimal manager incentive variables β_1 and β_2 from their profit function. Next, the managers simultaneously choose their optimal quantities of production q_1 and q_2 . In this

two-stage game, we apply backward induction to clearly show the profits and compensations of owners and managers. Thus, we analyze managers first, and then analyze owners. The inverse market demand function is given as:

$$p = a - b(q_1 + q_2), \text{ if } 0 \leq q_1 + q_2 \leq a/b \\ = 0, \text{ otherwise.} \quad (1)$$

where p is price, $a, b > 0$, and q_i is firm i 's output, for $i = 1$ and 2. The owners' objective functions are given as:

$$\pi_1 = \pi_1(\beta_1, \beta_2) = (a - bq_1 - bq_2 - c_1)q_1, \quad (2)$$

$$\pi_2 = \pi_2(\beta_1, \beta_2) = (a - bq_1 - bq_2 - c_2)q_2, \quad (3)$$

where π_i , for $i = 1$ and 2, is profit and c_i , for $i = 1$ and 2, is marginal cost. We also assume that, $a > c_i$ for both firms to participate in the market. The owners, having perfect foresight of the managers' games, consider managers' production quantities, q_1 and q_2 , and maximize their profits indirectly by appropriately choosing β_1 and β_2 , which determine the incentives for managers. Thus, the owners' profit functions π_1 and π_2 are dependent on β_1 and β_2 , and managers' incentives are proportional to:

$$M_1 = M_1(q_1, q_2) = \beta_1\pi_1 + (1 - \beta_1)R_1 = (a - bq_1 - bq_2 - c_1)q_1, [\beta_1 = 1] \quad (4)$$

$$M_2 = M_2(q_1, q_2) = \beta_2\pi_2 + (1 - \beta_2)R_2 = (a - bq_1 - bq_2)q_2 - \beta_2c_2q_2, \\ [\{\beta_2 | \beta_2 \leq 1\}] \quad (5)$$

Here, M_i , $i = 1, 2$, is the managers' compensation from the owners, for $i = 1$ and 2. Manager 1 of firm 1 maximizes only profits, assuming that owner 1 sets $\beta_1 = 1$ to induce manager 1 to maximize profits. Owner 1 prefers to maximize profits because of the characteristics of SMEs (firm 1), as explained previously. As owner 1 gives $\beta_1 = 1$ to manager 1, manager 1's objective is technically the same as that of owner 1: the maximization of profit (π_1). Although the assumption that $\beta_1 = 1$ seems extreme, it is useful for the simplicity of comparing the profits of firm 1 before and after adopting blockchain technology. We also have that $\{\beta_2 | \beta_2 \leq 1\}$ because the owner of the dominant firm (firm 2) is interested in market shares, which is measured by revenue. The managers simultaneously choose their outputs knowing each other's objective function. Therefore, taking derivatives of Equations (4) and (5) with respect to q_i , the reaction functions of the managers are:

$$q_1(q_2) = q_1 = \frac{a - c_1}{2b} - \frac{q_2}{2}, \quad (6)$$

$$q_2(q_1; \beta_2) = q_2 = \frac{a - \beta_2c_2}{2b} - \frac{q_1}{2} \quad (7)$$

The pure Nash equilibrium for each manager is:

$$q_1(\beta_2) = \frac{a - 2c_1 + \beta_2c_2}{3b}, \quad (8)$$

$$q_2(\beta_2) = \frac{a - 2\beta_2c_2 + c_1}{3b}. \quad (9)$$

Substituting Equations (8) and (9) into Equations (2) and (3), we obtain:

$$\pi_1(\beta_2) = \frac{(a - 2c_1 + \beta_2c_2)^2}{9b}, \quad (10)$$

$$\pi_2(\beta_2) = \frac{(a - 3c_2 + c_1 + \beta_2c_2)(a - 2\beta_2c_2 + c_1)}{9b}. \quad (11)$$

Because we assume that $\beta_1 = 1$, we only need to consider β_2 . Owner 2 must choose an appropriate β_2 to maximize firm 2's profit. Taking the derivative of Equation (11) with respect to β_2 produces:

$$\beta_2^* = \frac{6c_2 - c_1 - a}{4c_2}. \quad (12)$$

Therefore, the subgame perfect Nash equilibrium of owners and managers is:

$$((\beta_1^*, \beta_2^*), (q_1(\beta_1, \beta_2), q_2(\beta_1, \beta_2))) = \left(\left(1, \frac{6c_2 - c_1 - a}{4c_2} \right), \left(\frac{a - 2c_1 + \beta_2 c_2}{3b}, \frac{a - 2\beta_2 c_2 + c_1}{3b} \right) \right). \quad (13)$$

Substituting β_2^* into Equations (8) and (9), the Nash equilibrium output is:

$$q_1^* = \frac{a - 3c_1 + 2c_2}{4b}, \quad (14)$$

$$q_2^* = \frac{a - 2c_2 + c_1}{2b}. \quad (15)$$

As expected, the optimal output level of the SME that is not interested in market shares (firm 1) is relatively small compared to the optimal output level of the dominant firm (firm 2) when their marginal costs are similar, although this result can be inverted depending on their marginal cost difference. Accordingly, the subgame perfect Nash equilibrium output can be written as:

$$((\beta_1^*, \beta_2^*), (q_1^*, q_2^*)) = \left(\left(1, \frac{6c_2 - c_1 - a}{4c_2} \right), \left(\frac{a - 3c_1 + 2c_2}{4b}, \frac{a - 2c_2 + c_1}{2b} \right) \right). \quad (16)$$

Substituting the subgame perfect Nash equilibrium output into the owner's profit functions, $\pi_1(\beta_1, \beta_2)$ and $\pi_2(\beta_1, \beta_2)$, gives:

$$\pi_1 = \frac{(a - 3c_1 + 2c_2)^2}{16b}, \quad (17)$$

$$\pi_2 = \frac{(a - 2c_2 + c_1)^2}{8b}. \quad (18)$$

For the managers, M_i is given as:

$$M_1 = \frac{(a - 3c_1 + 2c_2)^2}{16b}, \quad (19)$$

$$M_2 = \frac{(a - 2c_2 + c_1)^2}{4b}. \quad (20)$$

As in the case of the output levels, firm 1's profit is smaller than that of firm 2 if the firms have the same marginal cost. However, because the square root of each firm's profit is affected by its own marginal cost reduction on the order of three times (firm 1) or two times (firm 2), we can expect that blockchain technology reduces costs more effectively for firm 1 than for firm 2. It is noteworthy that even the compensation of manager 2, who has an incentive to maximize revenue, is consequentially proportional to the firm's profit.

From now on, we assume that firm 1, the manufacturing SME, implements blockchain technology. Now, owner 1 does not have to consider incentives for manager 1 because she can supervise manager 1 in real time owing to the real-time transparency of blockchain technology. Instead, owner 1 directly sets the optimal quantity, q_1 , in stage 1, and manager 1 merely follows by producing the planned q_1 in stage 2. Firm 1, the SME, therefore preemptively achieves profit maximization in stage 1. However, as a market-dominating manufacturing firm, firm 2 still maximizes revenue. For firm 2, owner 2 selects an appropriate β_2 in stage 1, and manager 2 chooses the optimal q_2 in stage 2. Note that owner 1, with perfect foresight regarding stage 2, chooses q_1 in stage 1 knowing the optimal q_2 for

manager 2 (Table 1). Importantly, owner 2 cannot respond to q_1 with q_2 , but she responds with β_2 in order to render a manager 2's decision to the one owner 2 prefers, due to the lack of real-time transparency on manager 2. Meanwhile, manager 2 responds to the q_1 that is already set by owner 1 knowing the optimal q_2 , even though she is actually simultaneously choosing outputs with manager 1. Because of this time lag of the output decision of firm 2, firm 1 takes the advantage that is similar with being a Stackelberg leader owing to real-time transparency. We again apply backward induction by examining the manager first and then the owners.

Table 1. The actions of owners and managers.

	Owner 1	Owner 2	Manager 1	Manager 2
Stage 1 (Owner's game)	q_1	β_2		
Stage 2 (Manager's game)			Follows q_1	q_2

For these reasons, in the second stage, manager 2 of firm 2 maximizes her incentive in Equation (5):

$$q_2(q_1, \beta_2) = \frac{a - bq_1 - \beta_2 c_2}{2b}. \quad (21)$$

In stage 1, the owners' profits are:

$$\pi'_1 = \pi'_1(q_1, \beta_2) = \left(\frac{a - bq_1 + \beta_2 c_2 - 2c_1}{2} \right) q_1, \quad (22)$$

$$\pi'_2 = \pi'_2(q_1, \beta_2) = \frac{(a - bq_1 + \beta_2 c_2 - 2c_2)(a - bq_1 - \beta_2 c_2)}{4b}. \quad (23)$$

Owner 1 and owner 2 simultaneously choose q_1 and β_2 , respectively, to maximize their profits, which are:

$$q_1(\beta_2) = \frac{a + \beta_2 c_2 - 2c_1}{2b}, \quad (24)$$

$$\beta_2(q_1) = 1. \quad (25)$$

Thus, firm 2 no longer has an incentive for market domination because there is no competition in the second-stage game. The owner of firm 2 therefore places the full weight on profit maximization. The optimal outputs are derived from Equations (21) and (24) by replacing β_2 with 1:

$$q_1^* = \frac{a + c_2 - 2c_1}{2b}, \quad (26)$$

$$q_2^* = \frac{a + 2c_1 - 3c_2}{4b}. \quad (27)$$

As a result, the owners' profits in the equilibrium are:

$$\pi'_1 = \frac{(a + c_2 - 2c_1)^2}{8b}, \quad (28)$$

$$\pi'_2 = \frac{(a + 2c_1 - 3c_2)^2}{16b}. \quad (29)$$

Therefore, if π'_1 in Equation (28) is larger than π_1 in Equation (17), then firm 1 receives the benefits of real-time transparency and has incentives to implement blockchain technology. This condition is equivalent to:

$$\begin{aligned} \pi'_1 - \pi_1 &= \frac{(a+c_2-2c_1)^2}{8b} - \frac{(a-3c_1+2c_2)^2}{16b} > 0, \\ &\leftrightarrow \sqrt{2}(a+c_2-2c_1) > a-3c_1+2c_2. \end{aligned} \quad (30)$$

In fact, this condition always holds when all firms can make a profit in the market. The condition $\frac{5}{4}(a+c_2-2c_1) > a-3c_1+2c_2$ is equivalent to $a+2c_1-3c_2 > 0$, and this condition ensures a positive profit of firm 2, π'_2 . Because $\sqrt{2}(a+c_2-2c_1) > \frac{5}{4}(a+c_2-2c_1)$, Equation (30) is always satisfied, indicating that real-time transparency offers a profit. Moreover, this positive effect of real-time transparency on profits is smaller when firm 2's marginal cost, c_2 , is larger than firm 1's marginal cost, c_1 . This result arises because the difference in the square roots of π'_1 and π_1 is proportional to $\sqrt{2}(a+c_2-2c_1) - (a-3c_1+2c_2) = (\sqrt{2}-1)(a+c_2-2c_1) + (c_1-c_2)$. Thus, if firm 1 already has more competitive costs, then its profit may be insensitive to real-time transparency.

Assuming that their marginal costs are the same (i.e., $c_1 = c_2 = c$) for a more precise comparison, we find that:

$$\pi'_1 - \pi_1 = \frac{(a-c)^2}{8b} - \frac{(a-c)^2}{16b} = 2 \times \frac{(a-c)^2}{16b} - \frac{(a-c)^2}{16b} = \pi_1, \quad (31)$$

which is twice the original profit. Thus, the real-time transparency incentive for a profit-maximizing manufacturing SME is expected to be large enough to attract the SME to employ blockchain technology. In addition, by making preliminary production decisions utilizing real-time transparency, manufacturing SMEs can produce more outputs than before, and they can expect to earn greater profits than firm 2 can at a similar marginal cost level, which means $\pi'_1 > \pi'_2$.

$$\pi'_1 - \pi'_2 = \frac{(a-c)^2}{8b} - \frac{(a-c)^2}{16b} > 0. \quad (32)$$

Equation (32) is notable because it yields a contradictory result to that of Fershtman (1985) [10]. Fershtman (1985) [10] states that the earnings of a profit-maximizing firm are half those of a compromising firm. This reverse result is driven by the effects of real-time transparency; firm 1 can receive the benefit of preemptively deciding quantity and, thus, acting similar with a Stackelberg leader. This case is analogous to Basu (1995)'s [9] case of $(m_1, m_2) = (0, 1)$, which stackelberg leader firm 1 maximizes profits through not employing a manager. However, firm 1 in our case, technically employs a manager and produces in the stage 2. With the advantage of making a preemptive output decision through the blockchain technology's real-time transparency, SMEs can receive the benefits of becoming a leader and outperform a market-dominating firm even with a profit-maximizing strategy.

The application of blockchain technology not only provides real-time transparency to firms but also provides cost savings. Thus, as explained in Sections 3.1–3.3 and 4.1, blockchain technology helps firm 1 produce at a marginal cost less than c_1 , that is, c'_1 ($c'_1 < c_1$). However, developing blockchain technology in a firm may temporarily incur significant upfront costs. These upfront costs can be considered as one-time lump-sum costs. We define the expected cost savings (cs) realized by blockchain technology as, $cs = c_1 - c'_1$. Furthermore, we assume lump-sum costs (LC) as a certain ratio of the profits of firm 1 before applying blockchain technology, $LC = \gamma\pi_1$. Considering their characteristics, lump-sum costs are irrelevant to firms' optimal quantity choices and, thus, do not affect output decision makings but do affect profits. Therefore, π''_1 , the profits of firm 1 achieved by adopting blockchain technology, are as follows:

$$\pi''_1 = \pi'_1 - LC = \frac{(a+c_2-2(c_1-cs))^2}{8b} - LC, \quad (33)$$

Firm 1 has incentives to implement blockchain technology if the new profits, π_1'' , exceed the previous profits without blockchain technology, π_1 , even after considering lump-sum costs:

$$\pi_1'' > \pi_1 \leftrightarrow \frac{(a + c_2 - 2(c_1 - cs))^2}{8b} > (1 + \gamma) \times \frac{(a - 3c_1 + 2c_2)^2}{16b} \quad (34)$$

This inequality provides incentives for firm 1 to implement blockchain technology if the marginal cost savings are greater than the following lower bound:

$$cs > \left(\frac{\sqrt{2}}{4} \sqrt{1 + \gamma} - \frac{1}{2} \right) \times (a + 2c_2 - 3c_1) + \frac{c_2 - c_1}{2}. \quad (35)$$

The first term of the lower bound of cost savings, $\left(\frac{\sqrt{2}}{4} \sqrt{1 + \gamma} - \frac{1}{2} \right)$, implies that as more lump-sum costs are required, greater cost savings are needed, that is, as γ increases, greater cost savings are required. However, if, γ from the first term of the lower bound of cost savings is, $\frac{\sqrt{2}}{4} \sqrt{1 + \gamma} \leq \frac{1}{2} \leftrightarrow \gamma \leq 1$, the first term is non-positive, and, consequently, firm 1 has an incentive to employ blockchain technology even without any cost savings. This result arises because of the positive real-time transparency effects of Equations (30) and (31). More importantly, if γ is large enough that other terms besides the first term can affect Equation (35), as c_2 increases relative to c_1 , more marginal cost savings are necessary. This situation implies that because firm 1 is already receiving considerable profits (lower c_1 compared to c_2), it needs more lump-sum costs to have an incentive to implement blockchain technology. Furthermore, the profit from real-time transparency decreases with a larger marginal cost gap, as explained by Equation (30). As the profits of the manufacturing SME increase through the application of blockchain technology, manufacturing firms have incentives to employ blockchain technology.

4.3. Competition between Two Fairly Market-Dominating Manufacturing Firms, Only One of Which Uses Blockchain Technology

In this section, both firms compete for market domination because the two firms are equally large and competitive manufacturing firms. Thus, β_1 is no longer set equal to one. Instead, $\{\beta_1 | \beta_1 \leq 1\}$, and β_2 still satisfies $\{\beta_2 | \beta_2 \leq 1\}$. Thus, the owners in this game prefer managers to maximize revenues to secure a greater market share. This game follows the process described in Section 4.2. That is, owners choose managers' incentive variables first, with perfect foresight on managers' strategies, and, then, the managers choose the optimal quantities. However, we again use the backward induction method for analysis and, thus, analyze managers first. We first analyze both firms without blockchain technology, and then assume that firm 1 uses blockchain technology. The owners maximize profits using the objective functions given by Equations (2) and (3), and managers of firms without blockchain technology maximize:

$$M_1 = M_1(q_1, q_2) = (a - bq_1 - bq_2)q_1 - \beta_1 c_1 q_1, [\{\beta_1 | \beta_1 \leq 1\}] \quad (36)$$

$$M_2 = M_2(q_1, q_2) = (a - bq_1 - bq_2)q_2 - \beta_2 c_2 q_2, [\{\beta_2 | \beta_2 \leq 1\}] \quad (37)$$

The reaction functions of managers are:

$$q_1(q_2) = q_1 = \frac{a - \beta_1 c_1}{2b} - \frac{q_2}{2}, \quad (38)$$

$$q_2(q_1) = q_2 = \frac{a - \beta_2 c_2}{2b} - \frac{q_1}{2}. \quad (39)$$

The pure Nash equilibrium of each managers is:

$$q_1(\beta_1, \beta_2) = \frac{a - 2\beta_1c_1 + \beta_2c_2}{3b}, \quad (40)$$

$$q_2(\beta_1, \beta_2) = \frac{a - 2\beta_2c_2 + \beta_1c_1}{3b}. \quad (41)$$

Substituting $q_1(\beta_1, \beta_2)$ and $q_2(\beta_1, \beta_2)$ into Equations (2) and (3), we obtain:

$$\pi_1 = \pi_1(\beta_1, \beta_2) = \frac{(a - 3c_1 + \beta_1c_1 + \beta_2c_2)(a - 2\beta_1c_1 + \beta_2c_2)}{9b}. \quad (42)$$

$$\pi_2 = \pi_2(\beta_1, \beta_2) = \frac{(a - 3c_2 + \beta_1c_1 + \beta_2c_2)(a - 2\beta_2c_2 + \beta_1c_1)}{9b}. \quad (43)$$

Taking the derivatives of Equations (42) and (43) with respect to β_1 and β_2 , respectively, gives the owners' reaction functions, which are:

$$\beta_1(\beta_2) = \beta_1 = \frac{6c_1 - a - \beta_2c_2}{4c_1}, \quad (44)$$

$$\beta_2(\beta_1) = \beta_2 = (6c_2 - a - \beta_1c_1)/4c_2. \quad (45)$$

Thus, solving Equations (44) and (45) results in:

$$\beta_1^* = \frac{8c_1 - a - 2c_2}{5c_1}, \quad (46)$$

$$\beta_2^* = \frac{8c_2 - a - 2c_1}{5c_2}. \quad (47)$$

Substituting β_1^* and β_2^* into Equations (40) and (41), the subgame perfect Nash equilibrium output is:

$$\begin{aligned} & ((\beta_1^*, \beta_2^*), (q_1^*, q_2^*)) \\ & = \left(\left(\frac{8c_1 - a - 2c_2}{5c_1}, \frac{8c_2 - a - 2c_1}{5c_2} \right), \left(\frac{2a - 6c_1 + 4c_2}{5b}, \frac{2a - 6c_2 + 4c_1}{5b} \right) \right). \end{aligned} \quad (48)$$

As a result, owners' compensations are:

$$\pi_1 = \frac{2(a + 2c_2 - 3c_1)^2}{25b}, \quad (49)$$

$$\pi_2 = \frac{2(a + 2c_1 - 3c_2)^2}{25b}. \quad (50)$$

The managers' incentives are:

$$M_1 = \frac{4(a + 2c_2 - 3c_1)^2}{25b}, \quad (51)$$

$$M_2 = \frac{4(a + 2c_1 - 3c_2)^2}{25b}. \quad (52)$$

Because both firms use revenue maximizing incentives for managers, their profit scales are also symmetric, and their competitiveness depends on their marginal costs. Starting from this point, we again assume that firm 1 brings blockchain technology into its business. As in Section 4.2, owner 1 of firm 1, which now has blockchain technology, chooses the optimal quantity, q_1 , in stage 1. Then, in stage 2, manager 1 follows the decision of owner 1 because of real-time transparency. However,

the difference from the setting in Section 4.2 is that even though owner 1 prefers manager 1 to maximize revenue for market domination in this setting, because of the real-time transparency of blockchain technology, owner 1 can engage in a micro-management on manager 1, allowing her to act first on deciding a certain quantity. Thus, to gain the advantage of the faster decision making, owner 1 requires manager 1 to produce profit maximizing outputs. In the case of firm 2, owner 2 chooses the profit-maximizing β_2 in stage 1, and manager 2 selects the revenue-maximizing q_2 in stage 2 (the game procedure is the same as that described in Table 1). Thus, everything we consider is the same in Section 4.2 except for the profits of firm 1 without blockchain technology (now firm 2 is not the focus of our analysis).

Comparing Equation (28), the profits with blockchain technology, with the revenue-maximizing owner's profits without blockchain technology, Equation (49), the profits from real-time transparency are:

$$\pi'_1 - \pi_1 = \frac{(a+c_2-2c_1)^2}{8b} - \frac{2(a+2c_2-3c_1)^2}{25b} > 0, \quad (53)$$

$$\leftrightarrow a + 2c_1 - 3c_2 > 0.$$

Note that this condition is always satisfied as long as firm 2 remains in the market, that is, if firm 2 can earn positive profits according to Equations (29) and (50). Thus, Equation (53) shows, once again, the profits from real-time transparency. In addition, as shown in Section 4.2, the positive effects of real-time transparency on profits decrease as the marginal cost of firm 2 increases relative to that of firm 1. That is, $a + c_2 - 2c_1 = (a + 2c_2 - 3c_1) + (c_1 - c_2)$. This result implies that if firm 1 is already maintaining a good competitive position compared to firm 2, the compensation from real-time transparency decreases.

If we assume that the firms have the same marginal costs (i.e., $c_1 = c_2 = c$), the profit from real-time transparency, or the difference between π'_1 and π_1 , becomes:

$$\pi'_1 - \pi_1 = \frac{(a-c)^2}{8b} - \frac{2(a-c)^2}{25b} = \frac{25}{16} \times \frac{2(a-c)^2}{25b} - \frac{2(a-c)^2}{25b} = \frac{9}{16}\pi_1, \quad (54)$$

which is greater than the half of original profits. Consequently, significant profits can be obtained through the real-time transparency of blockchain technology, which can serve as an incentive to apply blockchain technology in the manufacturing industry.

Now, taking cost savings and the lump-sum costs of implementing blockchain technology into account, we define the decrease in the marginal cost due to blockchain technology as $cs = c_1 - c'_1$, and lump-sum costs are again $LC = \gamma\pi_1$. Recall Equation (33) for π_1 in Equation (49):

$$\pi''_1 > \pi_1 \leftrightarrow \frac{(a+c_2-2(c_1-cs))^2}{8b} > (1+\gamma) \times \frac{2(a+2c_2-3c_1)^2}{25b}. \quad (55)$$

The inequality in Equation (55) indicates firm 1's additional profits from the marginal cost savings of blockchain technology:

$$cs > \left(\frac{2}{5}\sqrt{1+\gamma} - \frac{1}{2}\right) \times (a+2c_2-3c_1) + \frac{c_2-c_1}{2}. \quad (56)$$

The first term in Equation (56), $\left(\frac{2}{5}\sqrt{1+\gamma} - \frac{1}{2}\right)$, implies that as the lump-sum costs of applying blockchain technology increase, (i.e., as γ increases) more cost savings are needed to finance these costs. However, if $\frac{2}{5}\sqrt{1+\gamma} \leq \frac{1}{2} \leftrightarrow \gamma \leq \frac{9}{16}$, the first term is not positive, and, in this special case, blockchain technology may be implemented even without cost savings. This free-looking benefit is induced by the profit increase from real-time transparency, as explained in Equations (53) and (54). Note that if γ is large enough and if c_2 is large compared to c_1 , more marginal cost savings are needed to justify the implementation of blockchain technology because firm 1 is already enjoying considerable profits, leading to higher costs for the blockchain technology implementation. This result coincides

with Equation (53). Again, the increase in the profits of the market-dominating manufacturing firm demonstrates that manufacturing firms have incentives to implement blockchain technology.

5. Implications and Conclusions

5.1. Implications: The Adoption of Blockchain Technology

The findings show that the real-time transparency and reduced costs achieved by blockchain technology help a manufacturing firm compete in the market by increasing its profits. As we have seen, not only can firms with smaller market shares increase their profits through the application of blockchain technology, but dominant manufacturing firms in a fairly competitive market can also benefit from implementing this technology. Thus, manufacturing firms have incentives to phase blockchain technology into their businesses.

Adopting blockchain technology not only increases a manufacturing firm's profits but also supports its ability to compete in the market. For example, a large firm's surveillance costs are normally greater than those of a small firm (Demsetz, 1983 [40]). If blockchain technology is adopted by small firms, such as in SMEs, as explained in Sections 4.1 and 4.2, their surveillance costs decrease. Thus, the cost gap between large firms and SMEs increases. Manufacturing SMEs can efficiently engage in a price war started by large dominant firms, given the advantages of real-time transparency and cost savings. Moreover, Catalini and Gans (2016) [15] contend that blockchain technology reduces networking costs. Networking costs are usually higher for small firms because large firms already have structured market platforms with various intermediaries and subcontractors. However, as small manufacturing firms reduce their networking costs by adopting blockchain platforms and developing new transaction platforms under blockchain technology, these firms can better compete with large manufacturing firms. These new transaction platforms possibly reduce surveillance costs because they use blockchain technology. Furthermore, small firms may be able to take advantage of network effects among the users of their blockchain platforms as the number of participants in these platforms increases. These costs effects of blockchain technology is especially important for SMEs, as, in the manufacturing industry, their costs are generally higher than that of large firms (Bain, 1954 [41]; Pratten, 1971 [42]). Overall, blockchain technology provides an opportunity for manufacturing SMEs to catch up with large manufacturing firms.

Blockchain technology may require substantial start-up costs because significant costs are required for IT-related preparations. However, we demonstrate in our model that, even after considering the lump-sum costs of implementing blockchain technology, a firm's profits may still increase when applying this technology because of real-time transparency and cost savings. CIOs may be reluctant to invest in blockchain systems unless a minimum return on investment is secured (Mougayar, 2016 [1]). Nevertheless, firms have incentives to introduce blockchain technology because they should consider the possibility of their competitors implementing blockchain technology. Not investing in blockchain technology is similar to not investing in projects generating positive NPV in the future for the sake of short-term gains, which proves to be detrimental in the long run.

Ustundag and Tanyas (2009) [43] explain that as the application of RFID technology to supply chains enhances transparency and efficiency, expected profits will increase. Likewise, blockchain technology is envisioned to increase the transparency of not only transactions but also an enterprise's internal systems. Thus, it may increase the expected profit of a firm.

In sum, owing to real-time transparency and cost savings of blockchain technology, manufacturing firms can be better off by implementing blockchain technology. Doing so will lead to the sustainability of firms in the manufacturing industry.

5.2. Limitations

Despite the positive arguments described above, blockchain technology is not a silver bullet that can solve all of the mentioned problems without any obstacles. This technology has some technological

(Bae, 2018 [44]; Kim, 2018 [45]; Seog, 2018 [46]) and legal issues (Kim, 2018 [45]; Marian, 2013 [47]). First, blockchain technology has an inherent flaw around the choice between transaction speed and retaining security. For example, the consensus algorithm may ensure more secure transactions as the percentage of user consensuses increases. However, waiting for consensuses from too many users reduces blockchain technology's advantage of simple and fast transactions, offsetting the benefits of cost reductions of blockchain technology. Another technological problem of blockchain technology is the confidence in the consensus algorithm. Recently, Verge, a cryptocurrency company with the 33rd highest aggregate value of coins, received a 51% attack from hackers (Kim, 2018 [45]). In the future, if supercomputers with much faster calculation speeds are developed, the nonce (the answer for hash value) of transaction can easily be hacked. This issue would destroy the integrity of blockchain technology, in turn, rendering the technology useless. In addition, if SETLcoin, described in Section 3.2, is traded through coin exchange institutions, the institutions may be hacked. In fact, the number of incidents of hackers shutting down the systems of cryptocurrency exchange institutions is increasing. These technological drawbacks of blockchain technology can threaten the applicability of blockchain technology in the manufacturing industry.

In addition, blockchain technology is considered to be tricky by some central governments, regarding legal issues such as the possibility of tax avoidance and criminal uses. Marian (2013) [47] specifies the tax problems of blockchain technology based on cryptocurrency transactions. Cryptocurrencies are traded through cyberspace account wallets, and the account users are anonymous, making it possible to avoid tax. Blockchain technology also allows transactions without bank intermediations, which can make it difficult for central governments to utilize banks to track tax avoiders. Furthermore, cryptocurrency users can upload temporary short messages on blockchain systems while making transactions. However, criminals often use this capability as a secret message platform. For example, sex offenders may upload links to pornography on blockchain systems. This practice causes secondary damage, that is, if an innocent person opens a link without knowing that it contains the pornography, the trace that he opened the link cannot be erased because of an irreversible feature of blockchain technology. These illegal uses of blockchain technology may dull the implementation of the technology.

5.3. Conclusions

This study investigates the implications of blockchain technology relating those to the sustainability of firms in the manufacturing industry, which is ensured by benefits in terms of real-time transparency and cost savings. First, blockchain technology helps to secure the integrity of a distributed system. At the same time, it enables real-time transparency and cost savings through the use of a consensus algorithm. Furthermore, blockchain technology is being developed in a wide range of industries. For example, the financial industry is working to implement blockchain systems in their businesses, such as SETLcoin, Ripple Lab, and NASDAQ. These applications of blockchain technology in the financial industry are expected to reduce the surveillance costs and remittance fees incurred as part of the business of manufacturing firms. Manufacturing industry supply chains are expected to be reformed by blockchain technology, which may reduce the verification and surveillance costs of manufacturing firms and enhance the quality of goods. Examples of supply chains that may utilize this technology include the composite material and agri-food supply chains. Applying blockchain technology to the manufacturing industry is expected to decrease manufacturing firms' networking costs and have network effects through the construction of new market platforms in the manufacturing industry. Furthermore, we compare the profits of manufacturing firms before and after adopting blockchain technology. The results show that manufacturing firms can increase their profits through two features of blockchain technology: real-time transparency and cost savings. In addition, we briefly explain that, owing to the real-time transparency and cost savings of blockchain technology, the profits of a manufacturing firm can exceed those of its rival firm. Thus, the effective adoptions of blockchain

technology in a manufacturing firm are suggested. Altogether, blockchain technology could support firms to sustain in the manufacturing industry through real-time transparency and cost savings.

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