Modeling the Welfare Effects of Blockchain in the Supply Chain

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ABSTRACT

Recently emerged in recent years, blockchain technology is a new form of data and service organization encrypting and exchanging all kinds of data by creating a new system of data validation. It is efficient for a group of people who do not trust each other but looking for integration and cooperation in a coherent decision-making process willing to find a common platform to share information. In the case of blockchain in terms of economics and economics of welfare, a question will be raised as to what will be the impact of such technology on the welfare of society. And whether it will necessarily have positive welfare effects due to its advantage. To answer this question, we will provide a competitive market modeling in two cases, with and without blockchain technology in the market (supply chain), which indicates that the welfare effects of the blockchain are generally positive, however, due to new costs imposed on manufacturers, it doesn't necessarily increase total welfare. The result may be influenced by the type of market, and under oligopoly or perfect competition marker conditions, social welfare may increase.

Keywords:

blockchain, consumer welfare, total welfare, supply chain.

1. Introduction

Recently emerged in recent years, blockchain technology is a new form of data and service organization encrypting and exchanging all kinds of data by creating a new system of data validation. It is efficient for a group of people who do not trust each other but looking for integration and cooperation in a coherent decision-making process willing to find a common platform to share information. Different definitions are presented for blockchain technology, each describing different aspects of it; however they use a general concept, simply stating that: "The blockchain is a distributed and decentralized ledger capable of storing large amounts of information about various transactions and making all this stored information available to all members of the network" (Nilfroshan and Ayazi, 2020).

Since 2008, when the concept of blockchain was developed by Satoshi Nakamoto as the main supporting component of digital currency transactions - Bitcoin - it has been known as a public ledger for exchanges that solved the double-spendpayment problem with public-key cryptography, by integrating peer-to-peer technology.

There are a series of detailed rules that control how a block is validated and ensure that it is modified or destroyed, and provide algorithms and computing infrastructure for creating, inserting, and using blocks for blockchain technology. Blockchain is a decentralized, distributed, shared, and immutable database ledger that records assets and transactions through a peer-to-peer network. It has a chain of data blocks that have been time-stamped and deposited by miners.

This technology uses elliptic curve cryptography and SHA-256 hash to provide strong cryptographic proof of data authentication and integrity (Salah & Khan,2018).

Some researchers consider three generations of blockchain as follows: a) Blockchain 1 for digital currency, b) Blockchain 2 for digital finance, and c) Blockchain 3 for the digital society. Blockchain 1 mainly consists of a blockchain-based data structure and a shared and widely used distributed ledger. Blockchain 1 mainly uses digital currencies and issues such as payments and currency exchange. Bitcoin is one of the first and most popular applications implemented on the blockchain infrastructure. Generally, its blockchain is currently the main technology and platform for many of the most popular cryptocurrencies. The Ethereum (ETH) blockchain was also come to live in July 2015 and opened for public use. Unlike the Bitcoin blockchain, which was mainly used for digital currency transactions, the Ethereum blockchain is capable of storing records and, more importantly, executing smart contracts. With the advent of the Ethereum blockchain capable of running smart contracts, the potential uses of the blockchain have become limitless. Therefore, Blockchain 2 mainly includes smart contracts and decentralized applications such as stocks, smart assets, and bonds. In addition to Ethereum, there are similar smart contract blockchain platforms including Hyperledger, Paris, Stellar, Ripple, and Tendermint.

Now, a question is raised in terms of economics and economics of welfare as to what will be the impact of such technology on the welfare of society. And does this inevitably lead to an improvement in the welfare of society? Or will it ultimately reduce the welfare of society due to the technical costs and necessary infrastructure changes?

.It has applications in a variety of areas, from cryptocurrencies and trading to automated machine-to-machine transactions, from supply chain and asset tracking to access control and automated sharing, and from digital identity and voting to certification and Data Management and Governance. As for the third-generation blockchain, it can be said that Blockchain 3 can be applied in all fields such as culture, art, medicine, and others, and will bring about a revolution in many fields. Therefore, it can be said that if there is more clarity in naming process factors and future transactions, blockchain can become an adopted norm in contemporary society.

To answer this question, we primarily start the modeling using the basic model without blockchain to explore how manufacturers determine prices, how sellers accept or reject manufacturers' orders, and how consumers make purchase decisions.

Literature

A blockchain is a decentralized, shared, and trusted ledger whose cryptography and distributed consensus mechanisms ensure the integrity of this ledger and enable all participants to agree on an unchangeable and unique version of the contextual truth. Blockchains include two types permissioned and permissionless. Permissionless blockchains based on decentralized protocols achieve consensus and theoretically may have unlimited participants or nodes. Due to the unknown identities of participants, permissionless networks are unreliable as they may discard old identities by having multiple identities and freely creating new ones. In contrast, permissioned blockchains have constraints in blockchain updates and node participation, and in some cases, provide complete transparency of nodes' identities.

No special permission is required to add information to the permissioned blockchain.This does not mean that the participant may add information without complying with some additional terms, but it does mean that additional terms cannot depend on the participant's identity. For example, some permissionless blockchains, such as Bitcoin, allow any node that solves the puzzle to add information to the blockchain by determining a computational puzzle. Such specifications not only provide some security guarantees even when the nodes are not trusted[1]but also inefficiencies such as the possibility of long-term disagreement about the content of the information stored in the blockchain[2]. Since the information on the blockchain is ambiguous due to these continuous disagreements, permissionless blockchains are particularly problematic in commercial environments because widespread ambiguity about the state of the system can be costly. Furthermore, as business environments typically involve frequent interactions among a set of economically motivated entities, a level of assumed trust is suitable.

The research literature examining the economic analysis of blockchains mainly deals with permissionless blockchains and esp. bitcoin. Some prominent research articles on Bitcoin include the study conducted by Yermak (2015), Biais et al. (2019), Easley et al. (2019), Foley et al. (2019), Griffin and Shams (2020), Capponi et al. (2021), Hinzen et al. (2021), Huberman et al. (2021), and Lehar and Parlour (2021). Beyond investigating Bitcoin, some important research topics in permissionless blockchains include designing and analyzing consensus protocols and smart contracts. As a first sample, many permissionless blockchains have recently launched proof-of-stake (POS) consensus protocols, and this has been reviewed in many recent articles conducted by researchers such as Fanti et al. (2019), John et al. (2021), Roseau and Saleh. (2021), and Saleh (2021). The code loaded in the blockchain is referred to as a smart contract, which generally includes methods implemented by the users of the related blockchain. Researchers such as Tinn (2018), Cong and He (2019), and Cong et al. (2021) in their prominent articles investigate the economic consequences of smart contracts in permissionless blockchains. One of the important applications of smart contracts is the asset offering known as Initial Coin Offerings (ICOs). A corporate loaded code is assigned to a typical ICO on a blockchain issuing a batch of coins in exchange for capital. Issuing conditions are generally specified directly in the smart contract code, which also guarantees the specific rights of recipients. Malinova and Park (2018), Catalini and Gans (2019), Lyandres et al. (2019), Howell et al. (2020), Li and Mann (2020), Chod and Lyandres (2021), and Gan et al. (2021) studied and investigated these mechanisms.

Compared to permissionless blockchains, permissioned blockchains have several key advantages that make them a more appropriate option for the supply chain management. Permissioned blockchains are typically more scalable and efficient. Moreover, permissioned blockchains can be customized for entities with common interests (such as a consortium of companies in a particular industry) making the participants capable of designing the governance structure. Most importantly, traceable supply chains require known identities of participants to provide transparency and traceability. As a result, the blockchain supply chain solutions must be permissioned and limited to known inventories, rather than infinite entry and exit permission. So, focusing on permissioned blockchains, we assume that only manufacturers can add information to the blockchain. Furthermore, as all transactions related to production are stored in the blockchain, the process is completely clear for all participants.

Widespread research has analyzed the economic implications of permissioned blockchains. In 2019 and 2020, Cao et al. (2019) and Cao et al. (2020) studied permissioned blockchains in the auditing field. Narang et al. (2019) study shows that permissioned blockchains facilitate online B2B collaboration under certain conditions. Pan et al. (2018) found out that blockchain can be used to fight the counterfeiting. In several other articles similar to the subject of this

[1] see Nakamoto 2008

[2] see Biais et al. 2019 and Hinzen et al. 2021

thesis, blockchains are studied in the specific field of supply chain management, which we discuss in more detail in Section 1.2.3.

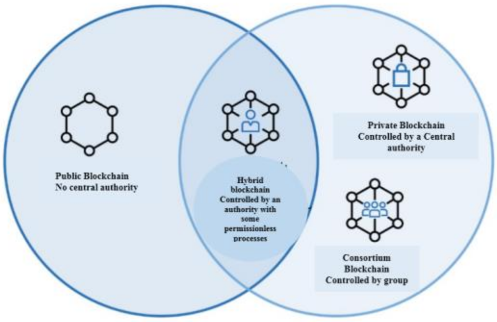

Figure 1-1. Types of Blockchain

Basic model

We consider a supply chain consisting of two sellers, limited manufacturers, and a consumer measurement unit. Sellers are vertically different while the manufacturers are both vertically and horizontally different. Consumers are heterogeneous in their preferences for horizontal differentiation among producers. Consumers order products from manufacturers who supply their goods from sellers.

$V := \{h,l\}, h > l \geq 0$ indicates the series of the sellers. The seller type $h\,(resp.\, l)$ (with low responsibility) is a type of seller with high (or low) responsibility. As discussed later, the seller type h has higher production costs compared to seller type l, and each consumer values more for the goods obtained from the seller of type h than the seller of type l. Furthermore, manufacturers are vertically differentiated along $\{h,l\}$, such that manufacturers of type h (*resp.* l) purchase vertically different from sellers of type h (*resp. type* l).

$M := \{1,2,\dots,4m\}$ is the set of manufacturers with $m \geq 2$[3]. Each manufacturer i has a two-dimensional type (q_i, ξ_i) where $q_i \in \{A,B\}$ corresponds to horizontal differentiation while $\xi_i \in \{h,l\}$ corresponds to vertical differentiation. Thus, A and B are categorical variables, while $0 \leq l < h$, as discussed earlier, so that manufacturers with $\xi_i = h(resp.\, \xi = 1)$ are of high responsibility type $(resp.\, low)$.

So, let M_i be a set of type $i \in \{A,B\} \times \{h,l\}$, we assume that $|M_i| =$ m was for all i and that all of these are common knowledge. We assume that the type of specific manufacturer is unknown to consumers and is a reflection of situations where consumers have relatively poor information. However, all results are applied equally regardless of whether manufacturers know each other's types or not[4].

Each consumer k $\in [0,1]$ also has $t_k \in \{A,B\}$ type with equal probability, and prefers goods from the manufacturer of his differentiated horizontal type (e.g., $q_i = t_k$ to $q_i \neq t_k$). Moreover, all consumers prefer high-type manufacturers (i.e. $\xi_i = h$) to low-type manufacturers (i.e. $\xi_i = l$). More formally, we assume in Transaction 3.1 that the random profit of consumer k from the consumption of goods by manufacturer i is as follows:

$$V_{ik} = \underbrace{\eta_{ik}}_{\text{Horizontal differentiation}} + \underbrace{\xi_i}_{\text{Vertical differentiation}}$$

In the above equation, η_{ik} indicates the means collected due to horizontal differentiation among manufacturers and $\xi_i \in \{h,l\}$ corresponds to the vertical differentiation type of manufacturers. η_{ik} is given explicitly in the following equation:

Equation (3.2):

$$\eta_{ik} = \mathrm{H.I}\,(q_i = t_k) + L.I((q_i \neq t_k)$$

In the above equation, $0 \leq L < H$.

We assume that consumers have access to signals that reflect the type of manufacturers. In particular, consumer $k \in [h,l]$ receives a set of random signals $\{(\tilde{q}_{ik}, \tilde{\xi}_{ik})\}_{i\in M}$ with $\tilde{q}_{ik} \in \{A,B\}$. We assume that $\mathbb{P}(\tilde{q}_{ik} = \mathrm{q}_i|\mathrm{q}_i) = \alpha = \mathbb{P}(\tilde{\xi}_{ik} = \xi_i|\xi_i)$, in this equation $\alpha \in [\frac{1}{2}, 1)$ so that a consumer signal does not completely reveal the specific type of manufacturer. Since all the main economic insights are available in the model with $\alpha = \frac{1}{2}$ and the representation is significantly simpler, we end up with $\alpha = \frac{1}{2}$ in the main text and Appendix A in this section. The main results are summarized in Appendix B. In the next section, we will discuss how blockchain affects consumer signals.

[3] The supply chain generally includes many participants such as multiple manufacturers of the same type, which is reflected in the required $m \geq 2$.

[4] see, e.g., Poole and Baron 1996

We also assume that every consumer may ignore purchasing from the manufacturer and instead use an external option. For consumer k ∈ [0, 1], the utility of the external option is ϕ_k, which is a random draw from a continuous distribution G supported on $[\cdot,\infty)$. This external option includes the opportunity cost of purchasing from a manufacturer and can reflect, for example, the utility of an alternative product.

In this section, we model a limited horizon economy. Primarily, they learn their utility from the external option ϕ_k and receive signals from each manufacturer. Then, all manufacturers act simultaneously, to determine the consumer priceP_i, $i \in M$, place the order to the seller of the vertically differentiated manufacturer type ξ_i, and offer a price to the seller $\Psi_i, i \in M$. The manufacturer's order to the seller is based on predicted demand, which is perfectly predicted in equilibrium since the research model has no general risk. After the manufacturer's actions, consumers act either on ordering the product from the manufacturer, if any, or choose from external options instead. Finally, each seller decides to accept, reject or partially fulfill each received order. Then, the seller agrees to produce all the goods agreed upon and sends them to the manufacturers to be transferred to the consumers.

More formally, seller h chooses i with $\xi_i = h$ for each order from the manufacturer by solving the following optimization equation, $\sigma_i \geq 0$ as follows:

Equation (3.3):

$$\max_{\{\sigma_i:\xi_i=h\}} \underbrace{\sum_{i=\xi_i=h} (\Psi_i.\sigma_i)}_{\text{expenditures}} - \underbrace{c_h\left(\sum_{i=\xi_i=h} \sigma_i\right)}_{costs}$$

$$s.t. \qquad 0 \leq \sigma_i \leq s_i \; for\ all\ i: \xi_i = h$$

In the above equation, $\Psi_i \geq 0$ indicates the price offered by the manufacturer i, $s_i \geq 0$ represents the expected demand of manufacturer i and $c_h(x)$ represents the seller's cost h of producing x units. This limitation shows that the realization level σ_i is the maximum consumer demand s_i.

Similarly, seller l faces the following decision problem:

Equation (3.4)

$$\max_{\{\sigma_i:\xi_i=l\}} \underbrace{\sum_{i=\xi_i=l} (\Psi_i.\sigma_i)}_{\text{expenditure}} - \underbrace{c_l\left(\sum_{i=\xi_i=l} \sigma_i\right)}_{costs}$$

$$s.t. \qquad 0 \leq \sigma_i \leq s_i \; for\ all\ i: \xi_i = l$$

In the above equation, $c_l(x)$ represents the cost of seller l to produce x units.

We assume that c_h is linear, while c_l is strictly increasing and convex. This assumption enables us to study strategic price adjustments due to blockchain adoption while maintaining traceability. In particular, the proposed assumption indicates that the pricing adjustments are only derived from the lower types, thus simplifying the analysis. By applying more discipline, we enable high and low-type manufacturers to coexist in equilibrium[5].

The manufacturer $i \in M$ by predicting the behavior of both seller and the consumer and solving the following problem that maximizes his net profit determines the consumer price P_i and the seller's price Ψ_i:

$$\max_{P_i,\Psi_i \geq 0} \underbrace{P_i.s_i}_{\text{expenditures}} - \underbrace{\Psi_i.s_i}_{costs} \qquad (3.5)$$

$$s.t. \quad \sigma_i = s_i$$

We assume that each manufacturer faces a large discretionary cost of not fulfilling the consumer's order, and thus must ensure that all predicted demand s_i is fulfilled, i.e., $\sigma_i = s_i$. Note that both σ_i and s_i are endogenously determined and both are influenced by the prices selected by manufacturers. Specifically, Equations (3.3) and (3.4) show that σ_i depends on Ψ_i, while s_i is a function of P_i, which we will discuss below.

After seeing the prices and the manufacturer signals, consumers decide to buy. The utility of consumer k, u_{ik}, for buying from manufacturer i is given by the following equation:

$$u_{ik} = \underbrace{\mathbb{E}[V_{ik}|\mathcal{F}_k]}_{value\ of\ expected\ product} - \underbrace{P_i}_{\text{cost}} \qquad (3.6)$$

5 We assume that $c_l'(0) < c_h'(0)$ so that the cost of the low-type manufacturer is low enough to keep the competition with the high-type manufacturer in equilibrium. We also require that $c_l'(G\left(\frac{H+L+h+l}{2} - c_h'(0)\right)) > c_h'(0)$, to ensure that the cost of the low-type manufacturer increases fast enough to enable the high-type manufacturer compete with the low-type manufacturer in equilibrium. Finally, we assume that $c_l(0) = c_h(0) = 0$ so that there is no cost for not completing the order.

In the above relationship, $\mathcal{F}_k$ represents the information set of consumer $k \in [0,1]$, which includes his type, the value of his external option, the type signal of each manufacturer, and the price posted by each manufacturer. Furthermore, as discussed, while consumer k does not know the type of any given manufacturer, public knowledge indicates exactly how many manufacturers m of each type exist, and consumers assume that each manufacturer is equally likely to be of any previous manufacturer type.

The consumer $k \in [0,1]$ purchases the goods from one of the manufacturers if his utility of doing this (weakly) exceeds his external option, that is, if $max_{i \in M}\, u_{ik} \geq \phi_k$. Let $i(k)$ be the manufacturer who provides his maximum utility, that is, $i(k) \in \arg\max_{i \in M} u_{ik}$. Then, consumer k purchases a good from manufacturer $i(k)$ if his utility from doing so (weakly) exceeds ϕ_k. Otherwise, he chooses the external option. By representing this option with $m(k)$, we see that $m(k)$ or i (k) or $\emptyset$. In this case, the consumer's endogenous demand for manufacturer $i \in M$, s_i, is:

$$s_i = \mu\left(\{k : m(k) = i\}\right) \qquad (3.7)$$

In the above relationship, $\mu(S)$ represents the size of a set $S \subseteq [0,]$ of consumers. Note that s_i depends on P_i because $m(k)$ depends on u_{ik} which in turn depends on P_i.

Model with blockchain

We strengthen the basic model with blockchain. Any manufacturer i may join the blockchain by paying a fee of $\chi_i > 0$. Let a_i be a binary decision-making variable that is set to 1 if producer i joins the blockchain, otherwise, it will be set to zero. We also assume that these decisions are publicly visible.

The existence of the blockchain changes the consumer's information environment: for each manufacturer i in the blockchain, the observed signal of each consumer $k \in [0,1]$ exactly represents the manufacturer's type. In other words, $\mathbb{P}(\tilde{q}_{ik} = \mathrm{q}_i | \mathrm{q}_i = \alpha_i = 1) = 1 = \mathbb{P}(\tilde{\xi}_{ik} = \xi_i | \xi_i, \alpha_i = 1)$.

This modeling option, with a major difference from the basic model, indicates the fact that the blockchain stores all aspects related to the production process and provides such information not only to manufacturers but also to consumers. Also, according to the main model, we assume that $\mathbb{P}(\tilde{q}_{ik} = \mathrm{q}_i | \mathrm{q}_i = \alpha_i = 0) = \alpha = \mathbb{P}(\tilde{\xi}_{ik} = \xi_i | \xi_i, \alpha_i = 0)$.

Similarly, we continue to model the economy with a limited horizon. Like the initial model, consumers primarily learn the types and their applications for the external option. Then, manufacturers simultaneously make blockchain adoption decisions before generating signals. As already discussed, due to the impact of blockchain on the distribution of signals, we determine blockchain adoption decisions before generating signals. After decision-making, each consumer simultaneously determines the consumer's prices observes the signals of each manufacturer such as the base model and gives the orders to the seller. Then, consumers decide, if any, from which manufacturer to order the required product; and not choosing a manufacturer means choosing an external option. Ultimately, each seller decides to accept, reject, or partially fulfill each production order received. Finally, each seller manufactures all the agreed goods and delivers them to the consumers by sending them to the manufacturers.

As in the basic model, the high- and low-type sellers solve Equations (3.3) and (3.4), respectively. On the other hand, the manufacturer problem is different between the model with and without a blockchain. Specifically, when deciding to adopt the blockchain, manufacturer i ∈ M solves the following equation to maximize profit:

$$\max_{a_i \in \{0,1\}} \prod(a_i, a_{-i}) - \chi_i a_i \qquad (3.8)$$

In the above equation, similar to equation (3.5), the expected profit, $\prod$ (a_i, a_{-i}), is obtained by the following equation:

$$\prod\ (a_i, a_{-i}) := \max_{P_i, \Psi_i \geq 0} P_i . s_i - \Psi_i . s_i \qquad (3.9)$$

In the above equation, $s_i \geq 0$ represents the determined endogenous demand of the consumer for manufacturer i. Note that s_i depends on a_i, a_{-i} as consumer demand depends on signals from each manufacturer, and as discussed earlier, signal accuracy depends on the decisions made by manufacturers.

As in the basic model, consumers observe prices and manufacturer signals and then make purchasing decisions accordingly. Consumers with blockchain see whether the manufacturer adopts the blockchain or not, so $\mathcal{F}_k$ also includes all adoption decisions; it means that seeing, per se, modifies the consumer's information environment. Consumers have detailed information about the types of manufacturers separately who join the blockchain. These changes in the consumer's information environment affect the observed endogenous demand of each manufacturer by affecting his decisions. Therefore, the specification of the consumer problem is the same as the original model, although u_{ik} now depends on whether or not the manufacturer has joined the blockchain.

Economic Analysis

In this section, we discussed the analysis of the total welfare of all participants in the supply chain. Three scenarios are considered, as follows:

a) Non-adoption: No manufacturer joins the blockchain, i.e. $a_i = 0$ for all $i \in M$.
b) Full adoption: Every manufacturer joins the blockchain, i.e. $a_i = 1$ for all $i \in M$
c) Partial adoption: Every high-type manufacturer joins the blockchain and no low-type manufacturer joins the blockchain. That is, $a_i = 1$ for all $i : \xi_i = h$ and $a_i = 0$ for all $i : \xi_i = l$.

Welfare in the non-adoption environment can be considered as a criterion against which the welfare of the other two can be measured because the non-adoption environment is the same as the original model without blockchain. This analysis indicates that full and partial blockchain adoption always benefits consumers rather than manufacturers. Also, it shows that full and partial blockchain adoption has ambiguous effects on total welfare. In the next section, we will examine the issue of whether blockchain adoption occurs in equilibrium or not, and found that neither full nor partial blockchain adoption occurs in equilibrium. Therefore, full blockchain adoption doesn't occur in equilibrium under circumstances, even if such adoption would increase total welfare. Such a situation is called adoption failure. Then, we propose a system of transfers to remove such failures.

Welfare concepts

We define seller welfare W_V, manufacturer welfare WM, consumer welfare W_C, and total welfare W as follows:

$$\mathrm{W_V} = \sum_{j:j\in\{h.l\}} \Big(\sum_{j:\xi_i=j} (\Psi_i \cdot \sigma_i) - c_j \big(\sum_{j:\xi_i=j} \sigma_i \big) \Big) \qquad (3 \cdot 10)$$

$$\mathrm{W}_c = \int_0^1 \mathbb{E}[max\{\max_{i\in M} u_{ik} \cdot \phi_k\}]dk \qquad (3.11)$$

$$W = W_v + W_M + W_c \qquad (3.12)$$

It is necessary to explain that in the analysis of all three scenarios, the blockchain adoption decisions are constant, but we determine all other values endogenously as complete equilibrium solutions of suitable subgames. More clearly, welfare analysis requires the determination of consumer prices, $\{P_i\}_{i\in M}$, seller prices, $\{\Psi_i\}_{i\in M}$; seller realization values for each manufacturer $\{\sigma_i\}_{i\in M}$, and the customer's demand for each manufacturer $\{s_i\}_{i\in M}$; we determine all these values with the endogenous assumption that manufacturers, sellers, and consumers act optimally in the subgame that results from the (constant) adoption decisions of manufacturers. Since all the quantities are different in the three cases, we will use the superscripts F, P, and N to refer to the cases of full adoption, partial adoption, and non-adoption, respectively.

Consumer welfare

Partial and full blockchain adoption always improves consumer welfare compared to the basic non-adoption model. In addition, full adoption provides higher consumer welfare than partial adoption, that is, $W_C^F \geq W_C^P > W_C^N$.

This result indicates a tangible improvement in consumer welfare with the adoption of blockchain. It is due to two effects. In particular, blockchain increases both the utility for each consumer who buys from a manufacturer and the general criteria for customers to buy from a manufacturer. A complimentary suggestion to formularize this point is as follows:

Let $M \coloneqq \{k \in [0,1]: m(k) \in M\}$ represents a set of consumers who buy from a manufacturer. We define $s \coloneqq \mu(M)$ and $u \coloneqq (\int_{k\in M} u_i(k)k\ dk)/s$ in such a way that s is the total demand of the consumer and u indicates the utility for each consumer among the consumers who buy from a manufacturer (i.e. k such that $k\in M$). Then, the following results are obtained:

Blockchain improves utility for a consumer who buys from a manufacturer who uses blockchain, i.e. $u^F \geq u^P > u^N$. Some consumers switch from the external option to buying from a manufacturer. Specifically, consumer demand increases with blockchain adoption, i.e. $s^F \geq s^P \geq s^N$.

The first effect is that the blockchain assures the accuracy of the signal received by each consumer from a specific manufacturer. Instead, each consumer may find a horizontal-type manufacturer of his own and also differentiate among distinct vertical manufacturers. The fact that consumers can differentiate between vertically differentiated manufacturers leads low-quality manufacturers to lower prices to survive in competition with high-quality manufacturers. Therefore, the first impact of it is in favor of consumers, because consumer decision-making not only improves more informed decision-making but also lowers the prices of low-quality manufacturers.

The second effect due to the increase in the purchasing utility for each consumer from a manufacturer leads some consumers, who would otherwise choose their external option, to optimally buy from a manufacturer. The resulting increase in consumer demand indicates a utility increase for any consumer who put aside external options because he only makes such a change if he receives a higher utility as a result of purchasing from a manufacturer.

Manufacturer Welfare

Full and partial blockchain adoption decreases manufacturer welfare compared to non-adoption, i.e. $W_M^F < W_M^P < W_M^N$.

This result indicates the permanent decrease in manufacturer welfare as a result of blockchain adoption as manufacturers are unable to extract consumer benefits due to its increasing prices, and competition in the manufacturing sector prevents the manufacturer from increasing prices. Furthermore, paying manufacturers to implement blockchain puts them in worse circumstances than adopting blockchain.

To understand it, we should know about the irreversible adoption of blockchain, while prices may always be changed, e.g., after deciding to adopt blockchain. By detailed modeling, we find that pricing decisions are made after adoption. It is always more profitable for a manufacturer to sell below the competitor's price as long as the unit price is higher than the unit cost. Therefore, manufacturers cannot raise prices above unit costs to internalize the benefits of blockchain adoption. In brief, after deciding between adoption, manufacturers are left with only the cost of adoption without compensatory profit.

Seller Welfare

Full and partial blockchain adoption reduces the seller welfare relative to non-adoption, for example, $W_V^F, W_V^P < W_V^N$.

This result shows a perceived decrease in seller welfare with the adoption of blockchain because it shows that low-quality manufacturers have low quality. Rather, the reaction of both low-quality and high-quality manufacturers is to lower prices to survive in the competition. Consequently, reduced prices are transferred to the low-quality seller, leading to lower profits for the low-quality seller. A complimentary suggestion to formalize this point would be as follows:

The price offered by low-type manufacturers to low-type sellers increases with the adoption of blockchain, that is, for all $i = \xi_i = l, \Psi_i^F, \Psi_i^P < \Psi_i^N$.

Total welfare

Blockchain adoption has ambiguous effects on total welfare. Let $\Delta := H - L$, then the following results hold.

Full adoption of blockchain can increase total welfare.

For a large enough Δ, the total welfare under full blockchain adoption is greater than the total welfare without it, namely, Δ exists in such a way that for all $\Delta > \Delta: \mathrm{W^F} > \mathrm{W^N}$.

Partial adoption of blockchain can increase total welfare

For a large enough Δ, the total welfare under partial blockchain adoption is greater than the total welfare without it, namely, Δ exists in such a way that for all $\Delta > \Delta: \mathrm{W^P} > \mathrm{W^N}$.

Full adoption of blockchain can reduce total welfare

For sufficiently large $\sum_{i:i\in M} \chi_i$, the total welfare under full blockchain adoption is less than the total welfare without it, i.e., χ exists in such a way that for all $\sum_{i:i\in M} \chi_i > \underline{\chi}$: $W^F < W^N$.

Partial adoption of blockchain can reduce total welfare

For sufficiently large $\sum_{i:\xi_i=\text{ı}}\chi_i$, the total welfare under partial blockchain adoption is less than the total welfare without it, i.e., χ exists in such a way that for all$\sum_{i:\xi_i=M}\chi_i > \underline{\chi}$: $W^P < W^N$.

This result shows the ambiguous effects of blockchain adoption on total welfare. The possibility of adopting blockchain to increase the total welfare is due to the improvement of the accuracy of each consumer's information by blockchain, consequently, leading each consumer to choose a manufacturer of the same type with a higher probability. The welfare profit of his choosing increases in $\Delta := H - L > 0$. This indicates that high Δ ensures consumer welfare when blockchain adoption increases enough to increase total welfare. Also, blockchain adoption generally reduces welfare due to all sufficiently high adoption costs. This result is simple because manufacturer welfare losses may be arbitrarily large by determining arbitrarily adoption costs.

Adoption Failures

There is no equilibrium in full or partial blockchain adoption. Specifically, manufacturer utility decreases while adopting blockchain, so manufacturers optimally decide not to adopt blockchain in equilibrium. It is because the benefits of blockchain mainly accrue to consumers, and also the competitive nature of the manufacturing sector prevents the extraction of sufficient benefits of consumer welfare to offset the costs of blockchain adoption.

It is necessary to explain that the failure of adoption refers to the situation in which blockchain adoption is not established in equilibrium even if the total welfare increases. The next result shows that adoption failures occur when Δ is large enough:

Adoption failure happens for sufficiently large $\Delta := \mathrm{H} - \mathrm{L}$.

Intuitively, there is an inconsistency between control over the adoption decision and the distribution of the welfare benefits resulting from that decision. It is necessary to explain that this result shows the tangible benefit of consumers due to adopting blockchain which increases with Δ; moreover, the consumers have access to this increased welfare for free. On the other hand, every manufacturer has no compensatory benefit when faced with an adoption fee, because even a small adoption fee will force him/her to join the blockchain. This rejection occurs anyway even if Δ is large enough to necessarily increase total welfare.

The research proposal is to provide a system of transfers by transferring part of the surplus welfare of consumers to manufacturers, which resolves the above-mentioned adoption failures. It is by charging a fee κ from consumers to access information in the blockchain and uses this fee by paying an amount to manufacturers $\tau_i \geq 0$. It is necessary for this transfer system to be autonomous (financed by the system itself); it means that the payment to the manufacturers is completely financed by the consumer's payments without any external finance, that is:

$$\kappa.\mu_k = \sum_{i:i=\in M} \tau_i \qquad (3.13)$$

In the above equation, $\mu_k \in [0,1]$ indicates the number of consumers who pay κ to access the information in the blockchain.

We modify the manufacturers' problem i to include the transfer payments, $\{\tau_i\}_{i\in M}$, as follows:

$$\max_{a_i\in\{0,1\}} \prod (a_i, a_{-i}) - \chi_i a_i + \tau_i a_i \qquad (2.14)$$

And also modify the problem k of the consumer so that it includes the cost κ of accessing the blockchain as follows:

$$\max_{b_i\in\{0,1\}} \mathbb{E}^{b_k}[max\,\{\max_{i\in M} u_{ik}, \phi_k\} - \kappa^{b_k}|\mathcal{G}_k] \qquad (2.15)$$

In this modified environment, the consumer k chooses his information environment $b_k \in \{0,1\}$ before observing the signals of manufacturers: $b_k = 1$ indicates the consumer's choice to access the information in the blockchain while $b_k = 0$ indicates the consumer's choice to ignore access to the information in the blockchain.

The information set of consumer $\mathcal{G}_k$ when choosing $b_k \in \{0,1\}$ includes the value of his external option, his type, and manufacturer prices and adoption decisions. Note that $\mathcal{G}_k$ does not include manufacturer signals as the decision $b_k \in \{0,1\}$ determines the distribution of manufacturer signals. In particular, by paying a fee of κ, the consumer k can receive more accurate type signals from any manufacturer joining the blockchain. Consumer k formally receives random signals of $\{(\tilde{q}_{ik}, \tilde{\tilde{\xi}}_{ik})\}_{i\in M}$ as $\mathbb{P}^{b_k}(\tilde{q}_{ik} = q_i|q_i, a_i) = a + (1-a)a_i b_k = \mathbb{P}^{b_k}(\tilde{\tilde{\xi}}_{ik} = \xi_i|\xi_i, a_i)$.

In terms of b_k variables, the size of μ_k is the set of consumers who pay the access fee κ by $\mu_k = \mu(\{k: b_k = 1\})$. We should note that the transfer system $(\kappa, \{\tau_i\}_{i\in M})$ must be autonomous along with financing, that is, the relationship (3.13) holds. It is suggested that the transfer system overcomes adoption failures if it induces an equilibrium whereby all manufacturers adopt the blockchain (i.e. $a_i = 1$ for all $i \in M$).

For sufficiently large Δ, the existing transmission system overcomes adoption failures.

This result shows removing adoption failures using our proposed transfer system. It should not only be high enough to compensate the manufacturers' adoption costs but also be low enough to maintain some welfare benefits for some consumers. The increased welfare of manufacturers causes adoption, as it aligns blockchain adoption with manufacturers' incentives. At the same time, maintaining the welfare benefits of certain consumers ensures their willingness to pay for the blockchain information environment, which in turn enables the financing of transfers to manufacturers.

The proportion of consumers who buy from a manufacturer is lower than those we discussed in section 3.3.1 on full adoption as consumers in the former environment have free access to the information on the blockchain, while they have to pay for that access in the modified environment. Due to the access of consumers to the external option, this fee made some of them choose the external option, who previously bought from a manufacturer. However, as Δ increases, the payment becomes optimal for all consumers.

The current research provides a clear path for the greater adoption of blockchain. In industries where consumers benefit significantly from the information stored in the blockchain, may access some of it in exchange for financing the adoption of the blockchain in that industry. Such financial payments are related to transfer payments from consumers to manufacturers and thus facilitate blockchain adoption. The proposed system can implement a simple method using a web-based payment application created by a consortium of all manufacturers. Every consumer has access to relevant information about the production process only if he pays for it. As discussed, fees are set high enough as total fees to offset the costs of blockchain adoption, but not as much high as a few consumers bear the cost. The income obtained is shared among all the manufacturers and thus is consistent with the incentives of blockchain adoption.

Conclusion

The analyses performed in the previous sections lead to the conclusion that blockchain adoption, whether partial or full, always improves consumer welfare compared to the default model of non-adoption. Moreover, full adoption provides higher consumer welfare than a partial one. Blockchain improves the utility of a consumer who buys from a producer using blockchain. Full and partial blockchain adoption reduces the producer's welfare compared to non-adoption.

Also, full and partial blockchain adoption reduces the seller's welfare compared to non-adoption. The price offered by low-end producers to low-end sellers will increase with the adoption of blockchain. Although, blockchain adoption has ambiguous effects on global welfare, full or partial blockchain adoption does not arise in equilibrium. Adoption failure occurs for sufficiently large Δ≔H-L. For sufficiently large Δ, the existing transmission system overcomes adoption failures.

The mentioned results are established in the competitive market where there is full efficiency and any excess production cost is not justified for the producer. However, by generalizing this result to other markets, it can be stated that using blockchain will be ultimately in favor of the manufacturer and the overall welfare will increase; because the benefits of blockchain in relation to its costs can be significant for the manufacturer and seller. One of these examples is the possibility of recalling defective goods in the supply chain and preventing the increase of sales return costs, which can be done by applying blockchain. Therefore, in fully competitive markets, the government provided the public blockchain infrastructure for the production sector at its own expense, assuming that its use can lead to manufacturing efficiency and shift the production function upward with the technology factor.

Resources

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