How Will Blockchain Change the Market Structure?

Completed Research Paper

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Abstract

This paper examines the effect of blockchain technology on market structure of online business. We focus on two aspects of blockchain technology: 1) its potential of eliminating information asymmetry and mistrust between buyers and sellers; and 2) its increasing marginal value of networking. The first aspect relates to its capability of forming transparency, reducing verification cost and enforcing execution of contracts. The second aspect relates to the fact that it becomes harder to act maliciously with more players joining the blockchain, making it more valuable to every member.

We model players' decisions under monopoly, duopoly, and monopoly with a potential entrant. We assume that players can decide whether to deploy their own blockchain or just join the blockchain deployed by other players. Our findings suggests that in a monopoly market, low deploying cost and high mistrust level leads to high propensity of deploying blockchain. In a duopoly market, the adoption of blockchain may lead firms into a "prisoners' dilemma", in which both firms deploy its own blockchain, but earn lower profit than when there is no blockchain technology. In a monopoly market with a potential entrant, the blockchain technology lowers the entry barrier for the entrant by eliminating the reputation advantage possessed by the incumbent. The incumbent may (1) deploy the blockchain to deter the entry of new entrant; (2) deploy the blockchain and serve the entrant; or (3) join the blockchain deployed by the entrant, depending on different market conditions. This paper rationalizes the adoption trend of blockchain technology in the industry and provides insights on the future development direction.

Keywords: Blockchain, market structure, uncertainty, Bitcoin

Introduction

Blockchain, a distributed ledger managed in a decentralized manner, is drawing tremendous attention from both industry and academia (Aoyagi and Adachi 2018; Cong and He 2017). It was first popularized as the technology behind the cryptocurrency Bitcoin (Cong and He 2017). Although the applications of blockchain technology in other industries are still in early stages, this technology is widely believed to have disruptive power to many industries (Anthes 2018; Gammon 2018; Marr 2018a; Tapscott 2017). Incumbent players from various industries, such as IBM (Aitken 2017a), Alibaba (Xiao 2017), Maersk (Hacket 2018), Walmart (Aitken 2017b), and De Beers (Lewis 2018) and so on are all exploring potential application of blockchain technology in their industries, not to mention countless start-up companies seeking for new market opportunities. It is thus interesting to tentatively explore the following research questions: How will players, including both incumbents and potential entrants, respond to the blockchain technology? How will blockchain affect the market structure?

In this paper, we rely on economic theory to explain how two key features of blockchain technology – its potential of eliminating seller/product uncertainty and developing trust between buyers and sellers and its increasing marginal value of networking – affect firms' responses to this technology. Uncertainty, the degree to which the transaction outcome cannot be accurately predicted because of seller- or product-related factors, is a big impeding factor for online markets (Dimoka et al. 2012; Hong et al. 2014; Pavlou et al. 2007). Many mechanisms have been developed to eliminate uncertainty of online transactions, such as reputation systems (Pavlou and Dimoka 2006), free trial (Cheng and Tang 2010) and product diagnosticity techniques (e.g. text, pictures, videos and even VR technologies) (Pavlou et al. 2007). However, these approaches cannot fully resolve the uncertainty issue. On one hand, the reputation systems suffer from the manipulation of centralized platform, leading to fake reviews and review biases (Lappas et al. 2016); on the other hand, it benefits the sellers with accumulated reputation, but may hurt the new entrants without accumulated reputation. The effectiveness of product diagnosticity techniques is constrained by the information the seller can provide. In other words, the sellers cannot provide full information about a product if they cannot the whole supply chain (Pavlou et al. 2007).

Blockchain has the potential to mitigate uncertainty and enable “trustless trust” between buyers and sellers. The *Economist* named blockchain technology as the “trust machine”, claiming that blockchain would change how the economy works (Economist 2015). Blockchain technology reduces uncertainty and benefits traders in the following three ways:

1) As a distributed ledger, blockchain records all valid transactions among traders on the platform. These transaction records are transparent to platform members, and are hard to be altered once recorded. The validity of the transactions are verified by “authorized verifiers”. Certain consensus mechanisms (e.g. proof of work and proof of stake) ensure that the verifiers only record valid transactions onto the blockchain. Since the transaction histories are stored in a decentralized way, it is almost impossible to change the records once they are put on the blockchain. The transparency, publicity and immutability nature of blockchain prohibits traders from lying on their historical behavior and current status.
2) Blockchain technology has the potential to mitigate product uncertainty. Product uncertainty occurs because sellers do not master complete product information or cannot fully convey product information. By adopting blockchain technology, all participants of a supply chain can share information among each other. Thus blockchain enables the traceability of each product from the start of supply chain. Sellers can also master and convey much richer information to consumers, to mitigate product uncertainty and build trust. IBM, Walmart and Chinese retailer JD.com are collaborating to apply blockchain technology on food supply chain (Aitken 2017a). Blockchain technology is also used to trace diamonds from the point they are mined right up to when they are sold to consumers (Marr 2018b). Combining blockchain technology with product diagnosticity techniques, sellers can provide much richer product information to buyers than before and thus mitigate product uncertainty.
3) Blockchain enables the execution of smart contracts, which can help make business networks less susceptible to fraud (Aoyagi and Adachi 2018; Cong and He 2017; Holden and Malani 2017). Smart contracts are digital contracts allowing terms contingent on decentralized consensus that are self-enforcing and tamper-proof through automated execution (Cong and He 2017). With smart contracts, all transactions are executed automatically once the pre-transaction commitments are satisfied. For example, a buyer and a seller can make a contract contingent on product delivery time. When the products are delivered later than the commitment, a compensation fee would be automatically transferred from the seller’s account to the buyer’s account. Automated execution of smart contracts not only increases efficiency, but also deters malicious behavior. Up to now, the most prominent platforms for smart contracts are Ethereum and Hyperledger. Both platforms offer a Turing-complete programming language, allowing agents to write and execute smart contracts based on blockchain. Blockchain technology can benefit the reputationally disadvantaged sellers by building “trustless trust” between buyers and sellers.

Another key difference between blockchain technology and traditional techniques is the strong network effect. A blockchain network becomes more trustworthy with more participants joining it, because of the “decentralized consensus protocol” (Cong and He 2017). With more participants verifying the validity of transactions, it becomes harder to act maliciously, such as recording invalid transactions on the distributed ledger or altering the information written on the blockchain. For example, the Bitcoin blockchain, which adopts Proof-of-Work (PoW) as consensus protocol (Ma et al. 2018), is less likely to suffer from 51% attack with more players verifying transactions on the network. A larger number of participants also means that it’s easier to find transaction partners on the network, increasing the asset liquidity on the network.

The cost of deploying a blockchain platform, including network deployment and hardware deployment cost, varies a lot across industries. Deploying a blockchain network is becoming easier. On one hand, most permissionless blockchains, such as Bitcoin and Ethereum, are open source projects, on the other and, many high-tech companies now provide modularized blockchain service (e.g. IBM Hyperledger Fabric and Amazon AWS Blockchain). With the modularized services, a blockchain network can even be deployed within several minutes. In the industries operating online, such as cryptocurrency and digital games, we observe that many players are deploying their own blockchain, probably because of low deployment cost. In many other industries, such as food, drug and luxury goods industry, firms have to adopt IoT technology to track product information through supply chain. However, the IoT hardware is not only expensive, but also not instantaneously mature enough for deployment. Firms are investing a lot to develop blockchain-based technology. For example, the retail giant, Walmart, is proactively developing a gamut of blockchain solutions for its business, from a blockchain-based customer resale marketplace (Zuckerman 2018), to an army of autonomous robots controlled by blockchain (CCN 2018). Tech giants Alibaba and IBM rank top globally for number of blockchain patents filed (Huillet 2018).

Given the strong network effect and high hardware deployment cost of blockchain technology, the firms developing blockchain-based solutions may have strong incentives to supply them to other players to earn additional profits. Thus in order to benefit from blockchain technology, a firm can choose between deploying its own blockchain and joining the blockchain deployed by others. We can observe both options in the real world. For example, De Beers deploys its own blockchain to track diamond supply chain and fight with counterfeit diamonds and blood diamonds (Marr 2018b). Cooperating with IBM, 10 of the world's biggest companies, including Walmart and Nestlé, developed Food Trust project to track food worldwide (Nash 2018). The TradeLens project, a blockchain-enabled global supply chain network, started by Maersk and IBM, has attracted more than 90 organizations (IBM 2018).

In this paper, we study three market structures: monopoly, duopoly and monopoly with a potential entrant. Firms compete to maximize their profit by making blockchain adoption, pricing and entrance decisions. We allow firms to adopt blockchain technology by deploying its own blockchain or joining a blockchain network deployed by competitor. We develop game theory models to examine firms' best strategies. We find that in a monopoly market, industries with higher uncertainty and lower blockchain deployment cost are more likely to adopt blockchain. As is mentioned above, typical industries with low blockchain deployment cost include cryptocurrenty and digital contents industry. We do observe fast adoption of blockchain technology in these industries (e.g. Bitcoin and Spotify (Perez 2017)). We also observe industries with high (cost of) uncertainty enthusiastically exploring potential application of blockchain (e.g. MediLedger[1], Walmart (Aitken 2017a), De Beers (Lewis 2018)).

In a duopoly market, we assume that both firms have the same level of quality and uncertainty and firms compete in a Hotelling market. We find that there exist equilibria in which adopting blockchain is a dominant strategy, no matter whether their competitor adopts it or not. However, there also exist "prisoners' dilemma", meaning that the blockchain technology lead to lower profit, compared to the profit when there is no blockchain technology.

In a monopoly market with a potential entrant, we assume the entrant's product quality is the same as the incumbent's product quality. However, the potential entrant cannot enter the market because of reputation disadvantage, i.e., buyers' lower willingness to pay led by higher uncertainty and mistrust. We develop a sequential game to examine firms' entrance strategies and blockchain adoption strategies. We allow firms to choose between deploying his/her own blockchain and joining the blockchain network provided by the competitor. In order to simplify our model, we assume that there is no entrance cost.

We find that several equilibria may exist under different conditions. First, when the blockchain deployment cost is low, the potential entrant always enters and both players deploy their own blockchain. Again, this explains the proliferation of cryptocurrencies. With low cost of setting up a cryptocurrency network, people claim certain level of uniqueness and creates a new cryptocurrency.

Second, with low product differentiation level and moderate blockchain deployment cost, the incumbent deploys the blockchain and the potential entrant does not enter the market. In this case, if the incumbent did not deploy the blockchain, the potential entrant would enter with blockchain and take away all the incumbent's market share. Thus, the incumbent deploys blockchain to deter the entrance of potential entrants.

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[1] https://www.mediledger.com/

Third, with higher product differentiation level and blockchain deployment cost, either the incumbent or the entrant deploys the blockchain. In this case, the blockchain deployer serves the competitors and act as a platform. This rationalizes the popularity of Hyperledger and Enterprise Ethereum Alliance. Members of both communities are giants from different industries, such as banking, insurance, airline, logistics and high-tech and so on. Only the giants can afford the high cost of deploying blockchain. The giants can also avoid being disrupted by providing blockchain service to others in their industry (i.e. Blockchain as a Service).

Fourth, with high product differentiation level and low uncertainty level, the incumbent does not adopting blockchain technology. While the entrant adopts blockchain technology, her entrance does not affect the incumbent a lot, since both players' products are differentiated and the incumbent already possess high reputation.

This paper contributes to the nascent literature on the effect of blockchain technology on market structure. Similar to Aoyagi and Adachi (2018), we focus on blockchain's capability of mitigating uncertainty and building trust between sellers and buyers. The equilibria deduced from out model provides certain level of rationalization for the adoption progress of blockchain technology in the industry. We also contribute to the literature on product and seller uncertainty by explaining how blockchain technology mitigates uncertainty and builds trust between buyers and sellers.

Literature Review

How Blockchain Develops Trust

Blockchain was first brought up by Satoshi Nakamoto as the infrastructure for Bitcoin, the most successful cryptocurrency up to now (Nakamoto 2008). The price of Bitcoin has increased from zero to thousands of U.S. dollars, with various cycles of appreciation and depreciation. Bitcoin has now become a medium of transaction and a store of value (Li and Wang 2017). Up to Feb 2015, Bitcoin had been accepted by over 100,000 merchants worldwide (Cuthbertson 2015).

The capability of Bitcoin to store value depends on its ability to develop trust among traders without intermediaries. Blockchain stores all valid historical transactions of Bitcoin in a distributed ledger, which is public to all users of Bitcoin. The validity of each transaction is verified by "authorized verifiers", who are incentivized to verify the transactions and put the valid transactions on the blockchain (Cong et al. 2018; Ma et al. 2018; Nakamoto 2008). Certain consensus mechanism, proof of work, ensures that the verifiers cannot act evil by putting invalid transactions on the blockchain (Ma et al. 2018). Since the distributed ledger is maintained in a decentralized manner, it is almost impossible to alter the transaction records once they are put on the blockchain. The security of users' accounts is guarded with cryptographic technologies. Through all these techniques, blockchain builds "trustless trust", which means transactions in Bitcoin systems are trustworthy without the need to trust anyone in particular (Werbach 2016). Overall speaking, traceability of authentic and immutable transaction records ensures the trustworthiness of traders on Bitcoin system.

Another successful application of blockchain is Ethereum. Different from Bitcoin, Ethereum is built with a Turing-complete programming language and thus enables smart contracts. Smart contracts are a set of promises, specified in digital form, including protocols within which the parties perform on these promises (Cong and He 2017). Contractual clauses of a smart contract are all distributed on the blockchain, so they are tamper-proof once set up. These clauses are executed automatically once the corresponding conditions are satisfied. With smart contracts, traders on Ethereum can set up state contingent transactions (Aoyagi and Adachi 2018). The execution of smart contract commitments is enforced by Ethereum protocols, so traders don't have to worry about the trustworthiness of others. While Blockchain systems producing cryptocurrencies (e.g. Bitcoin and Litecoin and Dogecoin) are called Blockchain 1.0; the blockchain systems enabling execution of smart contracts (e.g. Ethereum, EOS and Hyperledger) are called Blockchain 2.0.

Blockchain Based Trust and Traditional Trust Building Approaches

Online transactions are usually uncertain. Because of temporal and spatial separation, buyers are unable to either verify the trustworthiness of the seller or examine the product/service offline (Hortaçsu et al. 2009). Existing studies categorize uncertainty into seller uncertainty and product uncertainty (Dimoka et al. 2012;

Pavlou et al. 2007). Seller uncertainty describes buyers' difficulty in evaluating the seller's true characteristics and predicting whether the seller will act opportunistically (Dimoka et al. 2012). Product uncertainty is defined as the buyer's difficulty in assessing the characteristics of a product and predicting how the product will perform in the future (Pavlou et al. 2007). Three categories of solutions have been brought up to solve online uncertainty: reputation systems, diagnosticity techniques and third-party escrows.

Reputation Systems

Reputation systems allow consumers to provide feedback on the products they purchased or the service they experienced. Sellers obtain the trust of buyers by eventually accumulating their reputation. Consumers highly rely on reputation systems when they decide which seller to trade with. Sellers with higher reputation and more reviews are believed to be more trustworthy, and thus less risky to trade with (Babić Rosario et al. 2016; Burtch et al. 2017; Chevalier and Mayzlin 2006).

Reputation systems benefit popular sellers and popular products more than new entrants and new products, since the seller's trustworthiness is eventually accumulated through transactions and feedbacks. It is very hard for new entrants to rely on reputation systems to build trust. Moreover, current reputation systems suffer from fake reviews and deletion of negative reviews, impairing the overall trustworthiness of reputation systems (Anderson and Simester 2014; Lappas et al. 2016).

By contrast, blockchain systems ensures "trustless trust" between buyers and sellers, mitigating new entrants' reputational disadvantage compared to incumbents with high reputation. Moreover, blockchain technology has the potential to resolve the issues of fake reviews and deletion of negative reviews. Every transaction on blockchain is recorded on a shared ledger, and the system can be designed such that only consumers with purchase records can provide reviews. Deletion of negative reviews is prohibited with the immutability property of blockchain.

Diagnosticity Techniques

Diagnosticity techniques are intended to convey product relevant information and help consumers better evaluate a product/service (Pavlou et al. 2007; Yi et al. 2017). Diagnosticity techniques include text descriptions, photos, videos, third-party certifications and virtual reality techniques. The problem with diagnosticity techniques is that the authenticity of information provided by sellers cannot be easily verified, and that for products with complex supply chain, the sellers cannot master full product information. In these cases, even though sellers are honest, product uncertainty still cannot be eliminated.

Blockchain technology can enhance the effectiveness of diagnosticity techniques. By applying blockchain technology in supply chain management, complete information about the producing process of a product can be recorded, traced and shared. Information asymmetry can be reduced by allowing consumers to access full supply chain information.

Third-party Escrows

A third-party escrow is a financial arrangement where a third party (e.g. eBay and Taobao) holds and regulates payment of the funds required for a given transaction (Pavlou and Gefen 2004). It helps make transactions more secure by (1) keeping the fund in a secure escrow account which is only released when all terms of the transaction are satisfied, and (2) ensuring the safety of payment information, which cannot be easily obtained by sellers. The appearance of third-party escrows facilitates the development of e-commerce by making it safe to transact with unknown others. However, third-party escrows usually charge high commission fee for the transactions. For example, the commission fee in the hotel industry is between 10% and 30%, and more popular third-party escrows charge higher commission fee[2]. Moreover, penalties of traders' opportunism are usually executed by third-party escrows, which usually last for a long time and are costly (Pavlou et al. 2007).

[2] https://www.xotels.com/en/glossary/commission

Blockchain technology enables online transaction without third-party escrows, thus eliminating commission fee and saving much cost. Moreover, since all the transaction records are kept transparent, immutable and authentic, dispute resolution becomes much easier. It is predicted that blockchain technology may disrupt the business of third-party escrows.

Network Effects of Blockchain

Three properties of blockchain technology leads to its strong network effects. First, as is occurring on most permissionless blockchains, such as Bitcoin and Ethereum, the value of a native token increases as more participants adopt the blockchain (Catalini and Gans 2016). Thus the blockchain developers have the incentive to attract new participants to their own network. Second, the creditworthiness of the information recorded on the blockchain database is higher with more participants acting as verifiers (Ma et al. 2018). Third, since the blockchain database is stored in a distributed way, its robustness to cyber-attacks and single point failure gets higher with more participants (Cong et al. 2018). Overall speaking, the value of a blockchain network increases with the number of participants joining it.

Existing Studies on Blockchain

Existing studies mainly focus on technical details of blockchain, such as Bitcoin mining (Cong et al. 2018; Ma et al. 2018), consensus mechanisms (Saleh 2017), smart contracts (Cong and He 2017; Holden and Malani 2017) , and value of cryptocurrency (Aoyagi and Adachi 2018; Catalini and Gans 2018; Li and Wang 2017) and so on. There also exist studies on the overview of blockchain (Catalini and Gans 2016; Iansiti and Lakhani 2017; Michelman 2017; Tapscott 2017) and the applications of blockchain in different industries, such as supply chain management, crowdfunding, sharing market and so on (Babich and Hilary 2018; Gammon 2018; Potts and Rennie 2017; Sahdev 2017; Xu et al. 2017).

Our paper fits into the literature studying blockchain protocols, smart contracts and value of cryptocurrencies with game theoretic modelling approaches. Cong, He and Li (2018) studies the centralization and decentralization forces of Bitcoin mining. They show that while risk-sharing benefits attract independent miners to pools, leading to centralization, larger pools usually charge higher fees, leading to less miners to join and a slower pool size growth. Ma et al. (2018) maps Bitcoin mining into standard models of R&D racing, and shows that free entry, rather than endogenous level of computational difficulty built into the Bitcoin protocol, is responsible for determining the resource use for Bitcoin mining. While resource wasting of Bitcoin protocol is criticized by people, Saleh (2017) shows that another consensus mechanism, Proof-of-Stake (PoS), also induces consensus in equilibrium without consuming computational power. The effectiveness of smart contracts in mitigating information asymmetry and enhance commitment is discussed by Cong, He and Zheng (2018) and Holden and Malani (2017). Smart contracts can increase the contractibility and enforceability on certain contingencies, such as the lock-in requirement for fund withdrawal or the automated payment upon receiving the goods (Cong and He 2017). The ability of Blockchain to mitigate information asymmetry brings value to cryptocurrencies (Aoyagi and Adachi 2018; Catalini and Gans 2016; Davidson et al. 2016). Because of the security of the blockchain platform, the price and quality of assets traded in blockchain platform become higher than that in the cash market (Aoyagi and Adachi 2018). Catalini and Gans (2018) rationalizes the value of crypto-tokens by arguing that ICO (initial coin offering) can reveal consumer value without knowing consumer willingness to pay.

This study is closest to Aoyagi and Adachi (2018), which develops a model with coexistence of cash and cryptocurrency. While in the cash market, there is no way to detect low-quality products, leading to information asymmetry, in cryptocurrency market, the low-quality assets can be detected and excluded from the market before trading occurs with certain probability. They show that sellers with high quality will eventually go to the cryptocurrency market and charge higher price. This study also values the capability of blockchain technology to mitigate information asymmetry and develop trust. Rather than assuming coexistence of cash and cryptocurrency market, we study firms' adoption strategies of blockchain platform under different market structures (i.e. monopoly, duopoly and monopoly with potential entrants).

Model Development and Analyses

Monopoly Market

Without Blockchain

We start with the case where there is only one monopolist in the market. We assume that a monopolist **A** is located at point 0, with product quality Q. Consumers have no idea about the exact quality of the product. Perceived quality q_A conforms a normal distribution with mean Q and standard deviation δ_A. Consumers are assumed to be risk averse. Purchase utility of consumer i is described as $U_i = Q - \alpha\delta_A - \beta|d| - p_A$, where $|d|$ is the travel distance between consumer and seller, β describes consumers' traveling cost, and α describes consumers' risk averse level. Consumer i buyes one unit of product if $U_i \geq 0$.

Thus the seller's optimization problem can be written as:

$$\max_{p_A} \frac{2(Q - \alpha\delta_A - p_A)p_A}{\beta}$$

The optimal price is $p_{NC}^* = \frac{(Q-\alpha\delta_A)}{2}$, and the optimal profit is $\pi_{NC}^* = \frac{(Q-\alpha\delta_A)^2}{2\beta}$.

With Blockchain

Blockchain technology has the potential to mitigate uncertainty and build trust between sellers and buyers. In this paper, we assume that blockchain completely eliminates information asymmetry. In other words, consumers are acknowledged of the true quality Q and $\delta_A = 0$. Thus the seller's optimization problem can be written as:

$$\max_{p_A} \frac{2(Q - p_A)p_A}{\beta} - C_{BC}$$

Where C_{BC} is the cost of deploying blockchain. The optimal price is $p_{WC}^* = \frac{Q}{2}$, and the optimal profit is $\pi_{WC}^* = \frac{Q^2}{2\beta} - C_{BC}$.

Comparing the cases with and without blockchain, the seller gains a profit increase of $\Delta\pi = \frac{2Q\alpha\delta_A - \alpha^2\delta_A^2}{2\beta} - C_{BC}$. It is straightforward to observe that $\frac{\partial\Delta\pi}{\partial\delta_A} > 0$, thus the seller with higher prior quality uncertainty could gain more from adopting blockchain. Moreover, firms with lower cost of deploying blockchain are more likely to adopt this technology. As was discussed before, the cost of adopting blockchain differs across industries, mainly because of the cost of correctly mapping off-chain information with on-chain identities. Thus we predict that the blockchain technology would be first adopted by the industries selling digital goods, such as music industry (Perez 2017) and video-streaming industry (Granados 2018). Actually, the Open Music Initiative (OMI), composed of 200 members including the three major labels Sony, Music, and Warner, as well as YouTube, Netflix, Spotify, and Viacom, revealed in Jan 2018 on CNBC that it's considering blockchain as a foundational technology. Other industries with high cost of mistrust, such as food, drugs and luxury goods. Some examples including Walmart and IBM trying to ensure food safety by deploying blockchain based food supply chain (Aitken 2017a), De Beers turning to blockchain to ensure diamond purity (Lewis 2018), and Alibaba partnering with Moutai liquor to fight against fake liquors (Xiao 2017).

Duopoly Market

In this section, we develop a two stage simultaneous game to study firms' adoption decision of blockchain in a duopoly market. Following the Hotelling model, we assume that there are infinite number of consumers, who are uniformly located on an infinitely long Hotelling linear line with density of 1. The assumption of infinitely long line is to avoid end point problems and focus on our main analysis (Capozza and Order 1980; Mathewson and Winter 1984). We assume that there are two sellers **A** and **B**, located at point 0 and point l. Both sellers share the same product quality Q and the same perceived uncertainty level δ_{AB}. We assume that $l < \frac{3(Q-\alpha\delta_{AB})}{\beta}$ to make sure that sellers do compete with each other. Both sellers first simultaneously decide whether to deploy blockchain with cost C_{BC}, and then simultaneously make pricing decisions. Sellers' objective functions are given in Table 1.

Sellers would obtain competitive advantage if they adopt blockchain, but they also have to consider the cost of deploying blockchain. Table 2 shows both sellers' profits in different cases. Note that when $0 < l < \frac{3\alpha\delta_{AB}}{7\beta}$, the whole market share of the seller who does not adopt blockchain will be taken by the competitor who adopts blockchain. Comparing the profits in different cases, we obtain the following equilibria, which are visualized in Figure 1.

Proposition 1:

1) When (1) $0 < l < \frac{3\alpha\delta_{AB}}{7\beta}$ and $C_{BC} > \frac{Q^2}{2\beta} - \frac{3(\beta l - 2\alpha\delta_{AB} + 2Q)^2}{50\beta}$ or (2) $\frac{3\alpha\delta_{AB}}{7\beta} < l < \frac{3(Q-\alpha\delta_{AB})}{\beta}$ and $C_{BC} > \frac{51\alpha\delta_{AB}(14\beta l - 11\alpha\delta_{AB} + 28Q)}{2450\beta}$, neither **A** nor **B** adopts blockchain technology (Block D of Figure 1).
2) When (1) $0 < l < \frac{3\alpha\delta_{AB}}{7\beta}$ and $\frac{6\alpha\delta_{AB}(\beta l - \alpha\delta_{AB} + 2Q)}{25\beta} < C_{BC} < \frac{3(2Q+\beta l)^2}{50\beta}$ or (2) $\frac{3\alpha\delta_{AB}}{7\beta} < l < \frac{3(Q-\alpha\delta_{AB})}{\beta}$ and $\frac{6\alpha\delta_{AB}(\beta l - \alpha\delta_{AB} + 2Q)}{25\beta} < C_{BC} < \frac{51\alpha\delta_{AB}(14\beta l - 11\alpha\delta_{AB} + 28Q)}{2450\beta}$, both **A** and **B** adopt blockchain technology, but they earn less profit than when there is no blockchain technology (prisoners' dilemma) (Block B1 and Block C1 of Figure 1).
3) When $0 \leq C_{BC} < \frac{6\alpha\delta_{AB}(\beta l - \alpha\delta_{AB} + 2Q)}{25\beta}$, both **A** and **B** adopt blockchain technology, and they earn more profit than when there is no blockchain technology (Block B2 and Block C2 of Figure 1).
4) When $0 < l < \frac{3\alpha\delta_{AB}}{7\beta}$ and $\frac{3(2Q+\beta l)^2}{50\beta} < C_{BC} < \frac{Q^2}{2\beta} - \frac{3(\beta l - 2\alpha\delta_{AB} + 2Q)^2}{50\beta}$, there is no equilibrium (Block A of Figure 1). In other words, if one seller deploys (does not deploy) blockchain, then the other seller's best choice is not to deploy (is to deploy) blockchain.

Proposition 1 suggests that firms do not always benefit from adopting blockchain technology. Sometimes have to deploy blockchain to avoid being competitively disadvantaged. However, this may lead to lower profit when the cost of deploying blockchain is high, i.e., prisoners' dilemma.

Table 1 Seller's Objective Functions

		B: N	B: Y
A	N	$\max_{p_A}\left(\frac{Q-\alpha\delta_{AB}-p_A}{\beta}+\frac{l}{2}+\frac{p_B-p_A}{2\beta}\right)p_A$ $\max_{p_B}\left(\frac{Q-\alpha\delta_{AB}-p_B}{\beta}-\frac{l}{2}+\frac{p_A-p_B}{2\beta}\right)p_B$ $s.t.\ 0<\frac{l}{2}+\frac{p_B-p_A}{2\beta}<l$	$\max_{p_A}\left(\frac{Q-\alpha\delta_{AB}-p_A}{\beta}+\frac{l}{2}+\frac{p_B-p_A}{2\beta}\right)p_A - C_{BC}$ $\max_{p_B}\left(\frac{Q-p_B}{\beta}-\frac{l}{2}+\frac{p_A-p_B}{2\beta}\right)p_B$ $s.t.\ 0<\frac{l}{2}+\frac{p_B-p_A}{2\beta}<l$
	Y	$\max_{p_A}\left(\frac{Q-p_A}{\beta}+\frac{l}{2}+\frac{p_B-p_A}{2\beta}\right)p_A - C_{BC}$ $\max_{p_B}\left(\frac{Q-\alpha\delta_{AB}-p_B}{\beta}-\frac{l}{2}+\frac{p_A-p_B}{2\beta}\right)p_B$ $s.t.\ 0<\frac{l}{2}+\frac{p_B-p_A}{2\beta}<l$	$\max_{p_A}\left(\frac{Q-p_A}{\beta}+\frac{l}{2}+\frac{p_B-p_A}{2\beta}\right)p_A - C_{BC}$ $\max_{p_B}\left(\frac{Q-p_B}{\beta}-\frac{l}{2}+\frac{p_A-p_B}{2\beta}\right)p_B - C_{BC}$ $s.t.\ 0<\frac{l}{2}+\frac{p_B-p_A}{2\beta}<l$

Table 2 Seller's Profits under Different Strategies

		B: N	B: Y
A	N	$\pi_A^* = \frac{3(2Q+\beta l-2\alpha\delta_{AB})^2}{50\beta}$ $\pi_B^* = \frac{3(2Q+\beta l-2\alpha\delta_{AB})^2}{50\beta}$	$\pi_A^* = \begin{cases} \frac{3(14Q+7\beta l-17\alpha\delta_{AB})^2}{2450\beta} & when\ l > \frac{3\alpha\delta_{AB}}{7\beta} \\ 0 & when\ l \le \frac{3\alpha\delta_{AB}}{7\beta} \end{cases}$ $\pi_B^* = \begin{cases} \frac{3(14Q+7\beta l+3\alpha\delta_{AB})^2}{2450\beta} - C_{BC} & when\ l > \frac{3\alpha\delta_{AB}}{7\beta} \\ \frac{Q^2}{2\beta} - C_{BC} & when\ l \le \frac{3\alpha\delta_{A}B}{7\beta} \end{cases}$
	Y	$\pi_A^* = \begin{cases} \frac{3(14Q+7\beta l+3\alpha\delta_{AB})^2}{2450\beta} - C_{BC} & when\ l > \frac{3\alpha\delta_{AB}}{7\beta} \\ \frac{Q^2}{2\beta} - C_{BC} & when\ l \le \frac{3\alpha\delta_{AB}}{7\beta} \end{cases}$ $\pi_B^* = \begin{cases} \frac{3(14Q+7\beta l-17\alpha\delta_{AB})^2}{2450\beta} & when\ l > \frac{3\alpha\delta_{AB}}{7\beta} \\ 0 & when\ l \le \frac{3\alpha\delta_{AB}}{7\beta} \end{cases}$	$\pi_A^* = \frac{3(2Q+\beta l)^2}{50\beta} - C_{BC}$ $\pi_B^* = \frac{3(2Q+\beta l)^2}{50\beta} - C_{BC}$

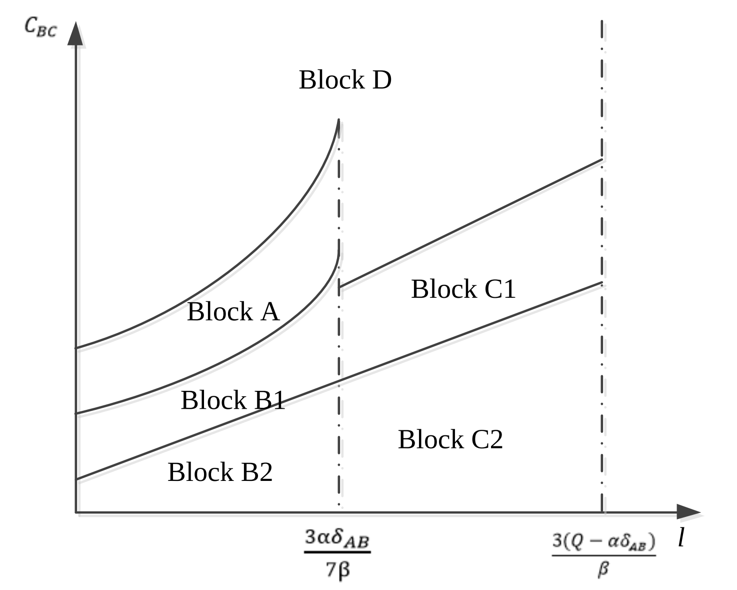

Figure 1 Visualization of Equilibria

Monopoly Market with Potential Entrant

In this section, we study how the blockchain technology brings new opportunities to potential entrants, who cannot enter the market without blockchain because of reputation disadvantage. Catalini and Gans (2016) mentioned that blockchain lowers the cost of mistrust, lowering entry barrier and facilitating entry of small players. It would be interesting to understand how the incumbents deal with the entrance of new players, and how they take advantage of blockchain technology to maximize their own benefit.

We assume that sellers can choose between deploying their own blockchain system and renting the blockchain service provided by competitor by paying a certain commission fee. Iansiti and Lakhani (2017) takes blockchain as future social and economic infrastructure, and compares it with TCP/IP. Through cautious design of cryptographic algorithms, access permissions and consensus protocols, it is possible for firms to enjoy the same blockchain infrastructure without revealing sensitive information (e.g. Hyperledger Fabric). The blockchain builder may also benefit from acting as a platform and serving the competitors, since she can then reach the consumers that cannot be reached by herself.

Similar to duopoly market, we also assume that there are infinite number of consumers, who are uniformly located on an infinitely long Hotelling linear line with density of 1. We assume that a monopolist **A** (hereafter called "he") is located at point 0, with product quality Q. There is also a potential competitor **B** (hereafter called "she") located at point l, with product quality Q. Perceived quality q_B conforms a distribution with mean Q and standard deviation $\delta_A + \delta$. We also assume that $\delta > 0$ to describe the fact that the incumbent seller enjoy better reputation than the new entrant.

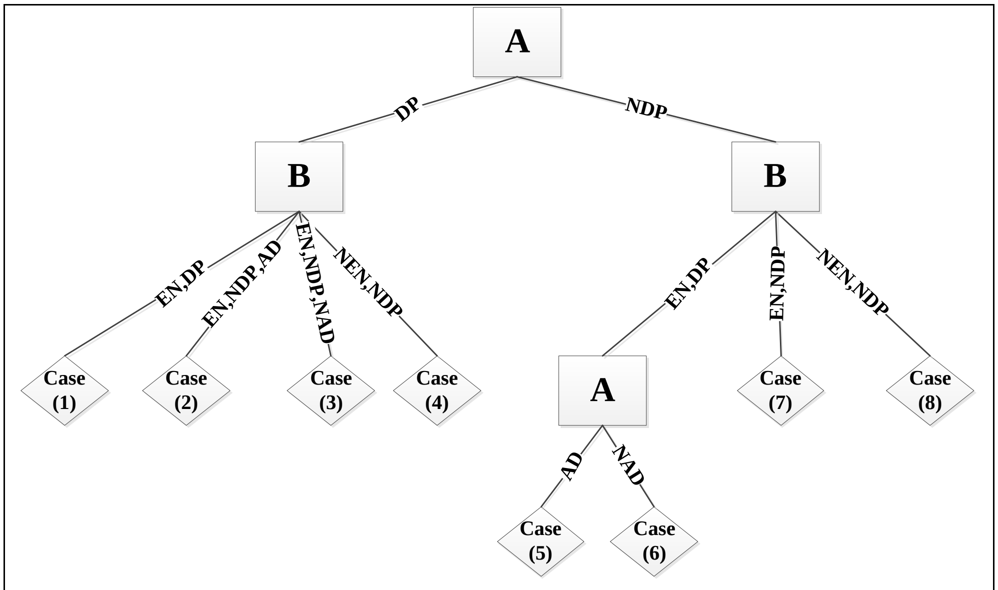

Figure 2 Extensive Form of the Sequential Game

Note: DP: deploying blockchain; NDP: not deploying blockchain; EN: entering the market; NEN: not entering the market; AD: adopting the blockchain service provided by competitor; NAD: not adopting the blockchain service provided by competitor.

We set up a four stage game, the extensive form of which is shown in Figure 2:

Stage 1: Seller **A** decides (1) whether to deploy the blockchain with cost C_{BC}, and (2) the commission fee f_{AB} to charge from seller **B**.

Stage 2: Seller **B** decides (1) whether to enter the market, (2) whether to deploy the blockchain with cost C_{BC} or adopt the blockchain service provided by **A**, and (3) the optimal commission fee f_{BA} to charge from seller **A**. Note that in order to simplify the model, we assume the entering cost is 0.

Stage 3: If **A** does not deploy the blockchain but **B** deploys the blockchain, Seller **A** decides whether to adopt the blockchain service provided by **B**.

Stage 4: Seller **A** and seller **B** simultaneously make pricing decisions.

We solve this sequential game with backward induction. In Stage 4, if **B** enters the market, then **A** and **B** compete in a Hotelling market; while if **B** does not enter the market, then **A** is still monopolist. For the sake of space, we only show the objective functions of **A** and **B** in Case (2), and other cases are similar:

$$\max_{p_A}\left(\frac{Q-p_A}{\beta}+\frac{l}{2}+\frac{p_B-p_A}{2\beta}\right)p_A$$
$$\max_{p_B}\left(\frac{Q-p_B}{\beta}-\frac{l}{2}+\frac{p_A-p_B}{2\beta}\right)(p_B-f_{AB})$$
$$s.t.\ \frac{p_B-p_A}{2\beta}<\frac{l}{2}$$

Table 3 demonstrates the optimal profits in each case. We assume that when there is no blockchain, **B** cannot attract any consumer because of reputation disadvantage, i.e., $Q-\alpha\delta_A-p_A^*-\beta l\geq Q-\alpha(\delta_A+\delta)-p_B^*$. Substituting the optimal prices into the formula, we get $l<\frac{3\alpha\delta}{7\beta}$. Thus Case (7) cannot happen. Case (3) cannot occur either, since Case (3) occurring means $l>\frac{3\alpha(\delta_A+\delta)}{7\beta}$, which can never be satisfied with the constraint of $l<\frac{3\alpha\delta}{7\beta}$. Intuitively, when the products are too similar, the new entrant cannot compete with the incumbent without blockchain technology because of reputation disadvantage.

Table 3 Optimal Profits When A Deploys Blockchain

	(1)	(2)	(4)
	BD; EN,BD	BD; EN,NBD,AD	BD; NEN
π_A^*	$\frac{3(2Q+\beta l)^2}{50\beta}-C_{BC}$	$\begin{cases}\frac{91(2Q+\beta l)^2}{876\beta}-C_{BC} & when\ l>\frac{62Q}{407\beta}\\ \frac{Q^2}{2\beta}-C_{BC} & when\ l\leq\frac{62Q}{407\beta}\end{cases}$	$\frac{Q^2}{2\beta}-C_{BC}$
π_B^*	$\frac{3(2Q+\beta l)^2}{50\beta}-C_{BC}$	$\begin{cases}\frac{361(2Q+\beta l)^2}{31974\beta} & when\ l>\frac{62Q}{407\beta}\\ 0 & when\ l\leq\frac{62Q}{407\beta}\end{cases}$	0

Table 3 Cont. Optimal Profits When A Doesn't Deploy Blockchain

	(5)	(6)	(8)
	NBD; EN,BD; AD	NBD; EN,BD; NAD	NBD; NEN
π_A^*	$\begin{cases}\frac{361(2Q+\beta l)^2}{31974\beta} & when\ l>\frac{62Q}{407\beta}\\ 0 & when\ l\leq\frac{62Q}{407\beta}\end{cases}$	$\begin{cases}\frac{3(14Q+7\beta l-17\alpha\delta_A)^2}{2450\beta} & when\ l>\frac{3\alpha\delta_A}{7\beta}\\ 0 & when\ l\leq\frac{3\alpha\delta_A}{7\beta}\end{cases}$	$\frac{(Q-\alpha\delta_A)^2}{2\beta}$
π_B^*	$\begin{cases}\frac{91(2Q+\beta l)^2}{876\beta}-C_{BC} & when\ l>\frac{62Q}{407\beta}\\ \frac{Q^2}{2\beta}-C_{BC} & when\ l\leq\frac{62Q}{407\beta}\end{cases}$	$\begin{cases}\frac{3(14Q+7\beta l+3\alpha\delta_A)^2}{2450\beta}-C_{BC} & when\ l>\frac{3\alpha\delta_A}{7\beta}\\ \frac{Q^2}{2\beta}-C_{BC} & when\ l\leq\frac{3\alpha\delta_A}{7\beta}\end{cases}$	0

Seller **B**'s strategy in Stage 2 depends on seller **A**'s choice in Stage 1. If seller **A** deploys blockchain, then **B** should decide whether to deploy her own blockchain, rent **A**'s blockchain service, or not enter the market. We have the following lemma:

Lemma 1:

When **A** deploys the blockchain:

(i) **B** deploys her own blockchain and enters the market if $C_{BC} < \frac{19468(2Q+\beta l)^2}{399675\beta}$.
(ii) **B** adopts **A**'s blockchain service and enters the market if $C_{BC} \geq \frac{19468(2Q+\beta l)^2}{399675\beta}$ and $l > \frac{62Q}{407\beta}$.
(iii) Otherwise, **B** does not enter the market.

If **A** does not deploy blockchain, then **B** has to deploy her own blockchain if she enters the market. **A** then decides whether to adopt **B**'s blockchain service in Stage 3. We have the following lemma:

Lemma 2:

When **A** does not deploy the blockchain:

(i) If $l < \min\left\{\frac{62Q}{407\beta}, \frac{3\alpha\delta_A}{7\beta}\right\}$ and $C_{BC} < \frac{Q^2}{2\beta}$, **B** enters the market by deploying blockchain and **A** earns zero profit.
(ii) If $\min\left\{\frac{62Q}{407\beta}, \frac{3\alpha\delta_A}{7\beta}\right\} < l < \min\left\{\max\left\{\frac{62Q}{407\beta}, \frac{3\alpha\delta_A}{7\beta}\right\}, \frac{3723\alpha\delta_A}{868\beta} - \frac{2Q}{\beta}, \frac{3\alpha\delta}{7\beta}\right\}$ and $C_{BC} < \frac{91(2Q+\beta l)^2}{876\beta}$, **B** enters the market by deploying blockchain and **A** adopts **B**'s blockchain service.
(iii) If $\min\left\{\max\left\{\frac{62Q}{407\beta}, \frac{3\alpha\delta_A}{7\beta}\right\}, \frac{3723\alpha\delta_A}{868\beta} - \frac{2Q}{\beta}, \frac{3\alpha\delta}{7\beta}\right\} < l < \frac{3\alpha\delta}{7\beta}$ and $C_{BC} < \frac{3(14Q+7\beta l+3\alpha\delta_A)^2}{2450\beta}$, **B** enters the market by deploying blockchain and **A** does not adopt **B**'s blockchain service.
(iv) Otherwise, **B** does not enter the market.

From Lemma 2, the key cut off point determining whether **A** adopts **B**'s blockchain service is $\frac{3723\alpha\delta_A}{868\beta} - \frac{2Q}{\beta}$, which is positively related to δ_A and negatively related to Q. Thus, **A** is more likely to adopt **B**'s blockchain service when his product uncertainty is higher and product quality is lower.

Lemma 1 and Lemma 2 are visualized in Figure 3. Block A represents the combination of Lemma 1-(iii) and Lemma 2-(i). In Block A, **A** always deploys blockchain, since if he does not deploy blockchain, **B** will always enter and deploy blockchain, taking away all his market share.

Block B represents the combination of Lemma 1-(i) and Lemma 2-(i). In Block B, **A** also deploys blockchain to keep his market share. However, because of low deployment cost, **B** still enters the market by deploying her own blockchain. Block A and Block B suggests that the incumbent always deploys blockchain if both sellers' products are too similar.

Block C represents the combination of Lemma 1-(ii) and Lemma 2-(ii). If **A** deploys the blockchain, then **B** adopts **A**'s blockchain service; while if **A** does not deploy the blockchain, then **B** deploys her own blockchain and **A** rents her service. We find that **A** deploys his own blockchain when $C_{BC} < \Delta_{2,5}$ and rents **B**'s blockchain service when $C_{BC} \geq \Delta_{2,5}$, where $\Delta_{2,5} = \frac{5921(2Q+\beta l)^2}{63948\beta}$.

Block D represents the combination of Lemma 1-(i) and Lemma 2-(ii). **B** always enters by deploying her own blockchain, no matter whether **A** deploys blockchain or not. **A** rents **B**'s blockchain service if he does not deploy it. However, further analysis suggests that **A** always chooses to deploy his own blockchain service.

Block E represents the combination of Lemma 1-(ii) and Lemma 2-(iii). If **A** deploys the blockchain, then **B** adopts **A**'s blockchain service; while if **A** does not deploy the blockchain, then **B** deploys her own blockchain and **A** competes with **B** without blockchain. We find that **A** deploys the blockchain when $C_{BC} < \Delta_{2,6}$, and compete with **B** without blockchain when $C_{BC} > \Delta_{2,6}$, where $\Delta_{2,6} = \frac{91(2Q+\beta l)^2}{876\beta} - \frac{3(14Q+7\beta l-17\alpha\delta_A)^2}{2450\beta}$.

Block F represents the combination of Lemma 1-(i) and Lemma 2-(iii). **B** always deploys her own blockchain. If **A** does not deploy the blockchain, he competes with **B** without blockchain. We find that **A** deploys the blockchain when $C_{BC} < \Delta_{1,6}$, and compete with **B** without blockchain when $C_{BC} \geq \Delta_{1,6}$, where $\Delta_{1,6} = \frac{3(2Q+\beta l)^2}{50\beta} - \frac{3(14Q+7\beta l-17\alpha\delta_A)^2}{2450\beta}$. Block E and Block F suggest that when bother sellers' products are differentiated, the entrance of new sellers do not affect the incumbent very much. Thus, the incumbent may be better off not adopting blockchain. Note that $\frac{\partial\Delta_{1,6}}{\partial\delta_A} > 0$, $\frac{\partial\Delta_{2,6}}{\partial\delta_A} > 0$, $\frac{\partial\Delta_{1,6}}{\partial Q} < 0$ and $\frac{\partial\Delta_{2,6}}{\partial Q} < 0$. This suggests that the **A** is more likely to compete with **B** without adopting blockchain when his product quality is higher and product uncertainty is lower.

Generally speaking, within each block of Block C, D, E and F, the incumbent deploys blockchain if the cost is lower than a certain threshold. Otherwise, the incumbent would either rent the blockchain service from the entrant, or compete with the entrant without adopting blockchain.

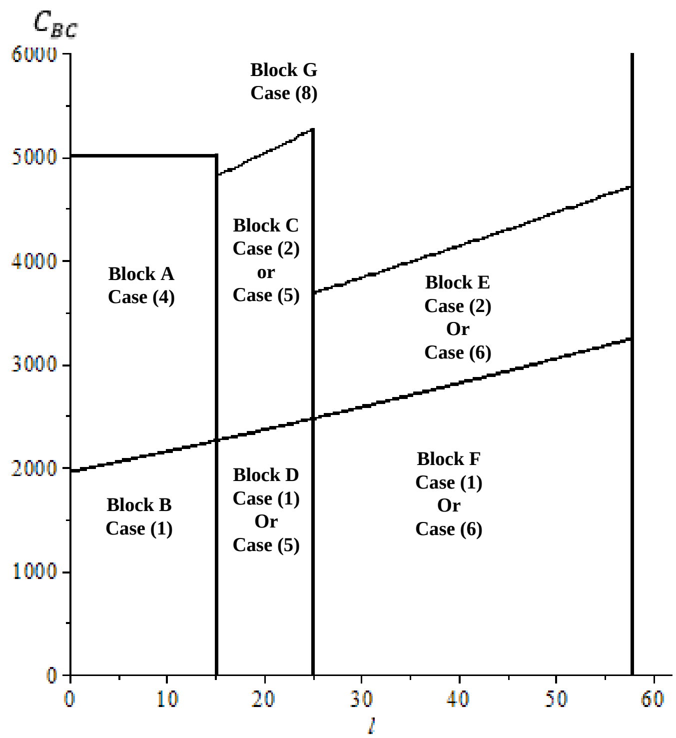

Figure 3 Illustration of Seller A's Choice Set

Note: $Q = 100, \delta_A = 35, \delta = 90, \alpha = 1.5, \beta = 1$

Figure 4 visualizes the final equilibrium. Overall speaking, blockchain technology facilitates entrance of the potential players who cannot enter the market without blockchain because of reputation disadvantage. Facing the entrance of new sellers, the incumbent may take different strategies, depending on product differentiation level, blockchain deployment cost and product uncertainty level.

1) In the industries with low C_{BC}, the potential entrant enters the market and both players deploy their own blockchain (Case (1)). This suggests that in the industries providing digital services, such as e-books, music and video streaming, and video game industries, we may observe many new entrants providing blockchain based services. Meanwhile, the incumbents will also actively adopt blockchain technology to maintain their market share. Low deployment cost of blockchain also explains the proliferation of cryptocurrencies. Since the source code of Bitcoin and Ethereum were put open-source, it is easy to learn and understand the code, revise the code to ensure certain level of differentiation, and then launch a new cryptocurrency.
2) In the industries with higher C_{BC} and low l, the incumbent deploys the blockchain service to deter potential entrants (Case (4)). Fresh food industry is featured with both high uncertainty and low product differentiation level. Giant players such as Walmart, Kroger and Nestle, are cooperating with IBM to explore the application of blockchain in fresh food supply chain (Aitken 2017b, 2017a).
3) When l and C_{BC} get higher, there exist equilibria in which either the incumbent or the entrant deploys the blockchain and serves the competitor, playing as a platform (Case (2) and Case (5)). Many high-tech large companies, such as Microsoft, IBM, Amazon and Oracle, are launching their "Blockchain as

a Service" or "BaaS" solutions, providing underlying supporting infrastructures for companies from other industries intending to adopt blockchain technology.

4) When l and C_{BC} are high, there also exist cases in which the incumbent does not adopt blockchain, but the entrant adopts blockchain (Case (6)).

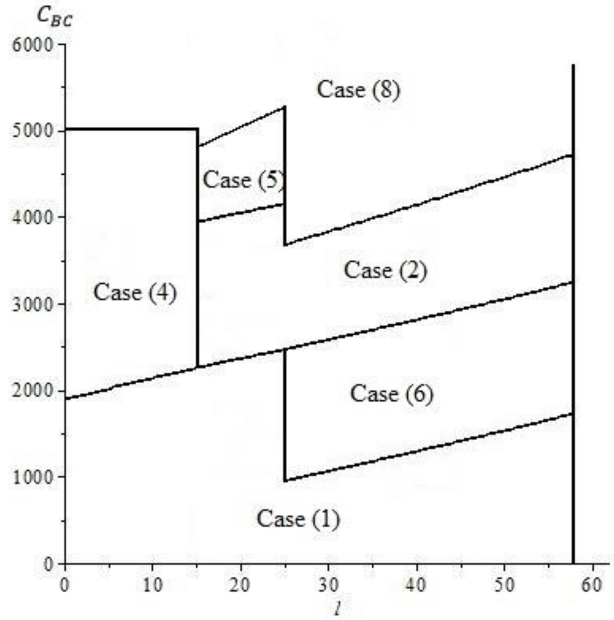

Figure 4 Illustration of Equilibria

Note: $Q = 100, \delta_A = 35, \delta = 90, \alpha = 1.5, \beta = 1$

Conclusion

Blockchain technology is gaining high popularity in both industry and academia. While this technology is yet not mature enough, and its business applications are still in early stage, people believe that blockchain will disrupt many industries in the future. Blockchain technology has several merits, such as decentralization, transparency, immutability and so on. Its ability to deploy trust among people without third party intermediaries, can be applied to many industries. In this paper, we study how firms under different market structures respond to the new technology, and how it would change the current market structure. Different industries differ in adoption cost of blockchain, product differentiation level and mistrust level. Our findings provides certain level of rationalization to the current adoption stages of blockchain technology in different industries. We show that blockchain technology is more actively explored in the industries with low adoption cost (e.g. cryptocurrency, digital contents, and video games) and high (cost of) uncertainty (e.g. food, pharmaceutical, and luxury good industry). We also show that in the industries with low adoption cost, both new entrants and incumbents will develop their own blockchain based separately. By contrast, in the industries with high adoption cost and high product differentiation level (e.g. high-tech, logistics, banking, and insurance and so on), the giant corporations will develop blockchain platform and serve other companies (i.e. Blockchain as a Service). Overall speaking, blockchain technology facilitates entry of small players by mitigating reputation disadvantage compared with incumbents. We also contributes to the literature on online trust and uncertainty by explaining how blockchain complements or substitutes current trust building approaches to mitigate uncertainty and build trust.

This paper is a general discussion on the effect of blockchain technology on market structure. However, in addition to deploying the blockchain and renting the blockchain service provided by others, firms also have to make more granular decisions. For example, firms may also have to decide whether to launch crypto-tokens when they provide blockchain based services. While Ethereum system is run with crypto-tokens, Hyperledger system is not. Firms also have to decide whether they want to launch an initial coin offering (ICO) campaign if they adopt crypto-token based blockchain system. All these decisions exert significant effect on firms' business models and market structures. Our future work will focus on these granular decisions, and what are the best decisions under different market structures.

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