Fundamental Values of Cryptocurrencies and Blockchain Technology

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Abstract

We propose a theoretical model to measure the fundamental values of cryptocurrency and blockchain technology. Due to its secure nature, blockchain allows the transactions to be state-contingent based on highly credible state information. In an economy with adverse selection, traders have an incentive to buy assets with unknown quality by using cryptocurrency to exploit the higher security of blockchain technology. This induces the demand for the cryptocurrency or access to the blockchain platform, determining the fundamental value of these new digital innovations. We also analytically demonstrate the effect of higher security of the blockchain technology: it leads to wider spreads in prices and qualities of assets traded via blockchain protocol and the traditional cash market. As well, it has a non-linear effect on the fundamental values of the cryptocurrency and blockchain platform, depending on the severity of underlying adverse selection. The welfare of agents is also derived, and it is shown to be collinear with the fundamental value of cryptocurrency.

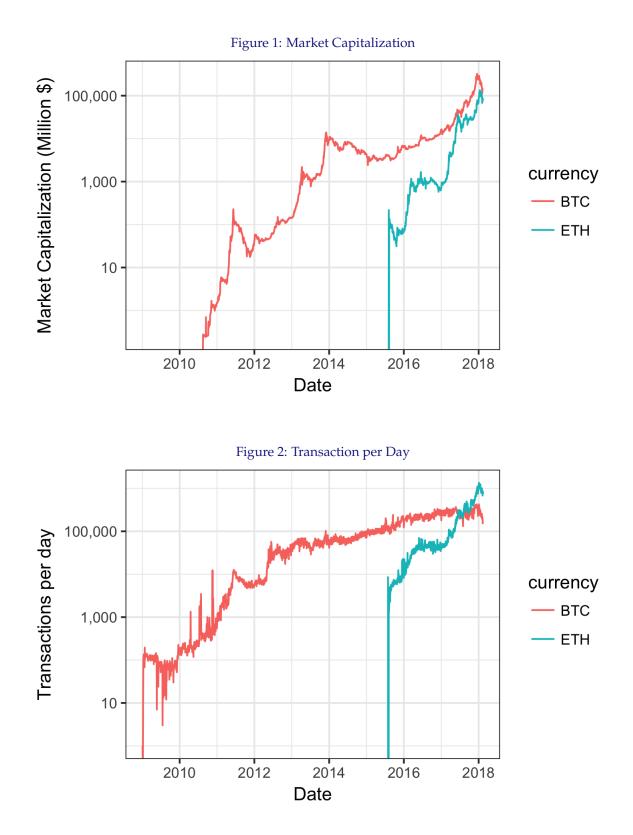
1. Introduction

In the financial market, the value of cryptocurrencies is rapidly growing. Figure 1 plots time series of market capitalizations of Bitcoin and Ethereum, the two largest cryptocurrencies in the digital currency market. The skyrocketing and highly volatile prices suggest that the traders seek the speculative opportunity, and so these reflect some bubble components. It is also possible, however, that there is some fundamental value in cryptocurrency. We can see first-pass evidence for the fundamental value in cryptocurrency by observing the increasing volume of transactions settled by using cryptocurrencies. For instance, Figure 2 shows the number of transactions per day executed through Bitcoin blockchain platform and that of Ethereum.¹

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¹As explained in Section 2., transactions through Ethereum better reflect the needs for the blockchain platform as an exchange where agents trade assets and information.



Based on these observations, what could be the fundamental value of these brand-new digital assets? How do we characterize the demand for cryptocurrencies out of speculative bets? We tackle these questions by understanding why market participants use cryptocurrency or blockchain platform as the mean of exchange rather than the traditional fiat money. That is, our central focus is on scrutinizing the fundamental difference of cryptocurrency from the fiat money as a mean of transactions. Specifically, we focus on the *state-contingent* transaction that is made possible by blockchain technology.

The state-contingency in cryptocurrency transactions is one of the most innovative aspects of blockchain protocol, and it makes cryptocurrencies fundamentally different from the fiat money (e.g., cash). If a transaction is executed by means of cash, there is no way to eliminate the asymmetric information a priori: possibilities of adverse selection and market break down are omnipresent. To reduce the problem, a typical economy relies on the intermediation by a credible third-party, such as banks, or agents purchase insurance to unload the risk. In other words, without any of these entities, the cash market suffers from the asymmetric information problems. In contrast, cryptocurrency is possibly immune from the adverse selection problem due to its secure nature of blockchain. As discussed in Section 2. in detail, transaction information stored in blockchain is strongly protected from tampering, *i.e.*, it is almost impossible to write fraudulent information and to rewrite the past information. It also allows the transactions based on complex scripts: users can write a code on the blockchain that describes the specific conditions they wish the transactions to fulfill. These features imply that the transaction can be state-contingent, *i.e.*, it is consummated if and only if a specific condition is satisfied, and the validity of "state information" is highly credible.

Therefore, in our model, we describe an economy with asymmetric information, in which agents decide which type of money (or transaction platform) to use to exchange assets of unknown quality. We claim that a transaction by means of cryptocurrency, founded on blockchain platform, bears less information asymmetry due to the blockchain technology and state-contingency of transactions. Because blockchain allows buyers to (partially) precludes low-quality goods or fraudulent counterparts, those who demand high-quality goods strongly desire to trade through blockchain platform rather than trading via traditional ways of exchange, such as cash. This argument tells why the cryptocurrency is demanded and valued even without speculative motives.

The first-half of the theoretical analyses concerns about the fundamental price of cryptocurrency. In this part, we focus on the class of cryptocurrency where a user of the blockchain platform has to hold the cryptocurrency in advance: the demand for it stems from the willingness to trade via the blockchain protocol.² For this purpose, we borrow the idea of cash-in-advance (CIA) constraint from monetary economics and make it "cryptocurrency-in-advance" to model the demand for blockchain platform.³ On the other hand, there are types of blockchain platforms that are not connected to cryptocurrency in this way (Section 2. provides examples of blockchains without cryptocurrency). For those class of blockchain platforms, the model offers the fundamental price (or value) of blockchain technology by measuring the welfare gain of traders that stems from adopting the blockchain trading system. Thus, our model provides the theory of fundamental value of blockchain, not restricted to cryptocurrency application. Interestingly, our model demonstrates that the value of the blockchain technology and the price of cryptocurrency (in the model with CIA) share the same factor as the determinant of their values: these values are perfectly correlated and identical up to positive affine transformation.

In the model, the coexistence of cash and cryptocurrency in the real world is captured by a model with multiple trading platforms. For exchanging an asset with unknown quality, there are two markets operated in parallel. In the traditional cash market (*C*-market), the fiat money, a numeraire in the model, is used as the medium of exchange. On the other hand, to purchase an asset in the blockchain platform (*B*-market), buyers must have cryptocurrency in advance. In the cash market, there is no way of detecting low-quality asset, and buyers have to accept the purchased products. In the blockchain platform, in contrast, the low-quality assets can be detected and excluded from the market before trading occurs with some probability θ , which captures the degree of security of the transactions via the blockchain technology.

²As discussed in detail in Section 2., this modeling represents the situation of initial coin offering (ICO) well: by investing and receiving the offered coins, buyers can make a transaction with sellers in the platform the ICO firm does.

³See Chapter 3 of the textbook by Walsh (2017) for a comprehensive discussion regarding CIA models in monetary economics.

More generally, the theoretical model analyses the effect of the segmented markets on the economy with adverse selection of Akerlof (1970). As the literature suggests, the segmentation of the trading venues endogenously causes the quality difference across the markets. Unlike the literature, however, our model tries to capture the effect of a security improvement provided by the blockchain. That is, we analyze how technological innovation in one market affects the quality and price in both markets, which, in turn, have an implication for the pricing of cryptocurrency.

If the innovation of blockchain breaks the symmetry across two markets, one direct and trivial consequence is the reduction of the low-quality assets in *B*-market: the quality of *B*-market improves. Moreover, the general equilibrium transmits this innovation and feeds back via the change in the behavior of agents in both of the sell- and buy-side. We show that the higher security (θ) in the blockchain platform increases the price of assets in *B*-market, widening the price and quality spread between *B* and *C*-market.

Given these differences in the average quality and prices, sellers face the price-liquidity (rejection) tradeoff. If a seller has a low-quality asset, the price improvement in the blockchain market comes at the expense of the risk of rejection. She fears the rejection risk because her low-quality asset has a low continuation value, *i.e.*, she must dispose her low-quality asset on her own if the blockchain rejects her selling attempt. On the other hand, if a seller has a high-quality asset, she sells it in *B*-market. Thus, the reaction to the innovation differs depending on the type of the seller's asset. This asymmetry in the behavior of seller facilitates the price and quality difference across two markets.

How do the buyers change their behavior? Analyzing buy-side reactions also sheds light on the effect of security improvement on the price of cryptocurrency. Specifically, the model shows that higher security (higher θ) of the blockchain protocol can decrease the price of cryptocurrency when the demand elasticity of the price is high. This result sounds counterintuitive but naturally arises from the decline in the demand for the cryptocurrency. To understand the mechanism, we need to know that buyers face the traditional price-quality trade-off. As θ increases, buyers have a stronger incentive to cluster in *B*-market to benefit from the higher average quality and expected return. On the other hand, the higher price in *B*-market due to the innovation makes buyers willing to migrate away from *B* to *C*-market. The cost of changing trading platforms depends on the difference in the average quality and the degree of adverse selection, *i.e.*, how bad the low-quality asset is compared to the high-quality asset. If the adverse selection is not severe or the quality difference across the markets is small, the higher price in *B*-market caused by the innovation wipes out a sizable amount of demand (elasticity is high), leading to the decline in the demand for cryptocurrency and its price.

Overall, by increasing the power of blockchain, it makes itself "an exclusive market for a high-quality and expensive asset." When the underlying difference between high and low-quality assets is small, the high price in the exclusive market confounds the buyers' incentive to buy in *B*-market. On the other hand, when the low-quality asset is extremely bad compared to high-quality ones, buyers accept the high price and purchase the high-quality assets guaranteed by the blockchain technology (elasticity is low). Only the latter case makes the price of cryptocurrency increase in the security of the blockchain and, more precisely, the price and transaction value of cryptocurrency take U-shaped curves if we take θ (security of blockchain) as the horizontal axes.

Furthermore, the model generates hypotheses regarding the welfare of traders. First, we show that the higher security of the blockchain does not necessarily improve the welfare of agents. Specifically, buyers and sellers endowed with low-quality assets can be worse off if the security of blockchain marginally improves, while it always improves the welfare of sellers of high-quality assets. The welfare of buyers can deteriorate if the higher price by the innovation kicks out traders from *B*-market and force them to accept the low-quality assets. Moreover, to quantify the fundamental value of blockchain itself, we also consider the blockchain manager who proposes the contract which enables traders to use the blockchain platform at some fee that traders pay *ex-ante*. The welfare gain is strictly positive if the agent obtains the access to the blockchain platform, and

this makes the willingness to pay the fee strictly positive. We argue that the strictly positive fee can be seen as the fundamental price of blockchain technology and show that its behavior has same implications as the price of cryptocurrency.

After a review of the related literature, Section 2 provides the overview of the technology of cryptocurrency and blockchain, and we also discuss our motivating examples. Section 3 introduces the theoretical environment and equilibrium of the economy with blockchain platform. Section 4 analyzes the comparative statics to understand the effect of higher security in blockchain technology. Section 5 conducts welfare analyses and shows the measure of the fundamental value of the blockchain. In Section 6, we propose the empirical hypotheses, and Section 7 concludes the discussions.

1.1. Related Literature

The current paper is in several strands of related literature. First, the research regarding blockchain technology and cryptocurrencies is growing recently. Huberman et al. (2017) take the Bitcoin as the leading example of cryptocurrency and analyze the determination of transaction fee and the overall system stability by focusing on congestion of Bitcoin payers. Biais et al. (2018) study the miners' fork incentives inherent in blockchain-based cryptocurrency by a model of coordination games. Bartoletti and Pompianu (2017) empirically examine the codes transacted in dominant blockchain network (mostly Bitcoin and Ethereum) and give a taxonomy of the transactions. As far as authors know, however, we are the first to analyze the demand for the cryptocurrency and blockchain by the asset buyers, their pricing, and connection to the welfare gain.

Among these studies, the work by Cong and He (2017) is closer to ours: they also consider the blockchain technology mitigates asymmetric information and adverse selection. They focus on the informational consequences of blockchain technology and argue that it improves welfare of consumers, while it can also lead to the collusion of sellers, since it becomes easier to punish the deviation based on the information recorded on the blockchain. Our model is different from theirs in many aspects, but most importantly, we consider the coexistence of the market founded on blockchain with the traditional one and the interaction between them. Incorporating the demand for the cryptocurrency, it provides finer investigations regarding the relationship between the security of blockchain, underlying adverse selection, welfare, trading volume, and asset prices, including the cryptocurrency price. In particular, we show that higher security can reduce the buyers' welfare due to the effect through changes in interrelated price and quality.⁴

The second strand of research related to this paper is about adverse selection that starts from Akerlof (1970). It is shown by the literature, such as Chen (2012), Kim (2012), Guerrieri and Shimer (2014) and Chang (2017), that the segmentation of markets leads to the quality difference across markets.⁵ We see the blockchain as the new platform to trade, alongside with the traditional cash market, and analyze the effect of market segmentation in the context of FinTech. Unlike the literature, in which the markets are homogeneous per se, our analyses argue how the different structure in one market (e.g., the degree of security, different mediums of exchange) affects the entire markets.

There is another strand of theoretical analyses on money demand, which are based on search theoretic foundations. Kiyotaki and Wright (1993) analyze the demand for worthless fiat durable money as the medium of exchange. Kocherlakota (1998) covers a broad environment with inability of commitment including Kiy-

⁴Khapko and Zoican (2016) also analyze the smart settlement by blockchain technology and argue that the technology makes it possible to settle the transaction in less costly and time-consuming manners, which is one of the other types of market incompleteness that blockchain can mitigate. Their focus is on the optimal time duration of the transactions under counterparty risk and search friction.

⁵Another dimension of the segmentation is the one across time, *i.e.*, traders can decide when to trade, as analyzed by Fuchs et al. (2016), Asriyan et al. (2017), and Fuchs and Skrzypacz (2017). Even though it does not reflect the real world in which both types of markets coexist, we believe that the implications of the blockchain technology are likely to be analogous even if we focus on the time dimension, *i.e.*, the market becomes blockchain platform at some timing in a single market economy.

otaki and Wright (1993) and discusses the relationship between money and memory. Compared to these modeling, we take the demand for cryptocurrency as a reduced form because we assume that the cryptocurrency is necessary for trading goods in a certain market (blockchain). This is because, in our model, what is critical is that the interdependence of price equilibrium in two heterogeneous markets and that the currencies used in each market are different. Microfoundation of "cryptocurrency in advance" is an important topic of future studies.

2. Technology Overview: Cryptocurrency, Blockchain, and their applications

In this paper, we focus on the cryptocurrency as a form of electronic currency that is backed by blockchain. Each participant in the network has an account with wallet, in which the balance of cryptocurrency is registered. The way of keeping track of each participant's balance is novel in cryptocurrency. The ledger of each participant's balance is not held by a particular entity but instead distributed across all nodes in the network. This distributed ledger system does not keep only the balance of the digital currency, but has all the past pieces of information, and requires them to be a consensus of all the participants of the network. Only if the participants agree, the information is considered to be relevant and recorded as a "truth." In general, it is extremely difficult for one participant of the network to overturn the consensus. In the case of Bitcoin, for example, system managers called miners leverage their computing power for the attempt to solve a time-consuming cryptographic problem. This process is called "proof of work," and the fastest miner who solves it becomes the one who adds a new block to the chain (or, simply, add new information to the system).⁶ Therefore, if a malicious agent in the network attempts to add fraudulent information to the transaction history, he has to outpace all miners in the network, which requires prohibitively high computing power.⁷

Once a set of transaction information forms a block, it is encrypted by "hash function" and passed to the next block to create a chain of blocks. The output of the hash function becomes different if one entity of input is different. Thus, revising a piece of information in a chain requires the revision of all of the subsequent information in the blockchain. As a result, any attempts to benefit from modifying the existing information is technologically impossible since, as mentioned above, it requires for the agent to have a huge computing power to make the mostly deceptive transaction record a consensus of the network. This is to say, only relevant information can be added to the blockchain, and it is free from tampering.⁸

Although the general properties of blockchain include tamper-proofness and state-contingency, the details that make these properties possible depend on each application. In the following subsection, we describe in detail major cryptocurrencies and the blockchain technologies that sustain them. In our model, a critical parameter is the security level of transactions in the blockchain platform, θ . Therefore, we place emphasis on the aspect of each example that guarantees the secure transactions.

2.1. Motivating Examples

As mentioned above, our model represents the secure nature of blockchain platform by using a parameter $\theta \in (0, 1]$. In this subsection, we provide a simple example to understand how we incorporate θ into our

⁶In Bitcoin blockchain, for instance, the difficulty of the problem is designed so that the average time for the new block to be added to the existing chain is 10 minutes.

⁷There are several ways to reach the consensus, and different blockchains adopt different processes. These include "proof of importance", in which the participant with the most intensive transaction record obtains the right to write the new information, and "proof of stake," in which the largest owner of the cryptocurrency is entitled to write the new information. Chiu and Koeppl (2017) provide the theoretical analyses to compare the efficiency of these processes.

⁸See Brummer (2015) or Harvey (2016) for a more comprehensive discussion.

general framework. Consider a two-periods' environment (t = 0, 1) in which risk neutral agents exchange an asset based on a sequence of past states denoted by s_0 . The state consists of states for individual agents: $s_t = (s_{t,i})_{i \in I}$, where $i \in I$ is the index for an individual player of the game. Instead of observing the true states of each other, an agent *j* can only see the announced state by her counterparties, denoted by $\hat{s}_{0,-i} = (\hat{s}_{0,i})_{i \neq i}$. In general, the true state $s_{t,i}$ is private information, and other agents $i \neq i$ cannot verify the validity of announced state $\hat{s}_{t,i}$. More concretely, consider a buyer (i = b) and seller (i = s) who meet each other at date t = 1 and try to exchange some assets based on the information of the historical state announced by each agent, \hat{s}_0 . We provide two examples to understand how blockchain technology can mitigate the asymmetric information.

2.1.1. Bitcoin

The leading example of cryptocurrency is Bitcoin. The idea of Bitcoin is first introduced by Nakamoto (2008), who proposes the blockchain technology for the first time. The part of the objectives of this proposal is to offer a solution to the "double spending" problem. Because only the transactions whose authenticity is guaranteed by the selected miner are regarded as correct, agents can agree on the correct transactions. Hence, when a malicious entity attempts to spend its currency holdings more than twice (double spending), only one of them is authenticated by the other agents, and so the attempts fail. Bitcoin is the first success after a long history of proposals of decentralized media of transactions, making it the largest market capitalization in the cryptocurrency trading market.⁹ (Narayanan et al., 2016)

Bitcoin blockchain has recorded the information of the flow of bitcoins across participants ("Alice paid X bitcoin to Bob") in a tamper-proof manner. In the model section, this secure nature can be captured by a parameter $\theta \in (0, 1]$. To have a concrete idea of the security in the example of Bitcoin, suppose that liquidity providers (buyers) have liquid assets (cash or bitcoin), and liquidity takers (sellers) are endowed with illiquid assets whose common value is k. At date t = 1, takers are hit by a liquidity shock and want to offload (liquidate) their asset holding to obtain (net) utility u(m) - k from liquid cash (or coin). The state of liquidity providers is either $s_{0,b} \in \{m, 0\}$, where $s_{0,b}$ represents the value of cash or bitcoin she holds. Suppose that $s_{0,b} = 0$ realizes (she already spent her cash or coin in the past) for $1 - \pi$ fraction of liquidity providers, and rest of them have $s_{0,b} = m.^{10}$

Since announcing $\hat{s}_{0,h} = m$ is strictly dominant for all of the buyers, $1 - \pi$ fraction of them are fraudulent who attempt to use the coin or money they already spent (double-spend). In the traditional cash market without a bank that monitors the accounts of her customers and transactions, fraudulent agents easily spend their money twice (or more) as long as $\pi u(m) > k$, because this inequality means that sellers want to sell the asset and transaction takes place.

On the other hand, in the Bitcoin's network, it is extremely difficult to spend the coin twice because even if the agent with $s_{0,b} = 0$ claims that $\hat{s}_{0,b} = m$ is the true state, this cannot be the agreement. We capture this by saying that θ fraction of $1 - \pi$ agents fail to accomplish their fraud transaction, which makes the fraction of honest sellers $\tilde{\pi} = \frac{\pi}{\pi + (1-\theta)(1-\pi)} > \pi$. This provides the higher expected return for liquidity takers and thus, they have an incentive to utilize blockchain platform rather than the cash transaction.¹¹ In the example of Bitcoin, θ is very high since the double spending is precluded as long as an agent has a prohibitively strong computing power.¹²

⁹As of Feb. 8, 2018

¹⁰Assume that π is common knowledge, and $m < k < \pi u(m)$ hold so that transactions take place. ¹¹Of course, knowing that θ fraction of "double spending" fails, the behavior of liquidity providers also changes. We do not go into detail of this point in this section and leave it for the formal analyses in Section 3.2.

¹²Kroll et al. (2013) show that there is a risk that distributed ledger system goes wrong by the group's attempt to make some information consensus. It is also shown by Biais et al. (2018) that the folk of the chain ends up with two (or more) different consensuses. We capture these events by $\theta < 1$.

2.1.2. Ethereum

As we will see, precluding double spending is not the only feature enabled by blockchain technology. It also allows us to write complex scripts to determine what kind of information is regarded and added as "relevant" one.¹³ The notion of the smart contract has been viral ever since Ethereum, the second largest blockchain network in its market capitalization, makes it possible to write a code for state contingent transaction. First, as mentioned earlier, the state information recorded on the blockchain is highly credible. Second, by writing codes such that "transaction takes place if and only if the state *s* satisfies conditions (1)..., (2)...., and (n)...," we can make the transaction contingent on our desirable conditions (1)-(n). This technology has many applications to mitigate frauds in the asset transaction and information storage and allocation.

Wine-blockchain, founded by EY consulting firm, is a juicy example. Traditionally, the wine market is exposed to the risk of counterfeit ("lemons" in the sense of Akerlof, 1970), whose economic losses amount to \$1-5 billion per year. The problem of low-quality wine is severe since many intermediaries are involved in the supply chain of wine, making it difficult to keep track of all the transactions from the ingredient firms to retail stores. By utilizing blockchain and smart contract, however, the transaction of wines is free from the lemons' problem without any credible third-party intervention.¹⁴

Suppose that there are expensive high-quality ingredient and cheap low-quality ingredient provided by different grape firms. If a wine producer mixes ingredients by π fraction of good ingredients, a produced box of wines contains π fraction of good wine and $1 - \pi$ fraction of bad wine. Each wine producer has a state $s_{0,s} = \pi \in [0,1]$ which represents how intensively she used the high-quality ingredients. Since wines in the same box are labeled as the same, consumers cannot distinguish bottles of bad wine, and this arises an incentive for wine producers to make $\pi < 1$. In the traditional market, to reduce the risk of the low-quality wine, agents build a reputation or long-run relationship, or consumers directly go to wineries to taste bottles. The other possibility is buying insurance or paying fees to ask a credible third party to be a witness of the transaction. In both cases, it takes a sizable cost in terms of money or time. Now, we write a code such that "cryptocurrency paid by consumers will be transmitted to the wine firm only if the firm bought the ingredient exclusively from a good firm: $s_{0,s} = 1$." The information in the latter part ("a wine firm bought ingredients" from a high-quality grape firm: $s_{0,s} = 1''$) can be easily verified in a credible manner under the blockchain mechanism. We view θ as how completely we can write the script on the blockchain to eliminate the lowquality products.¹⁵ Because it is not plausible to assume that agents can make the transaction of products (or ingredients) in all the steps accept only high-quality products, we guess it is reasonable to assume that $\theta \in (0,1].$

2.2. Connection of Blockchain and Cryptocurrency

The two examples above use the cryptocurrency as the mean of transactions through the blockchain platform. This class of blockchain platforms includes the one for transactions of wines (EY, based on Ethereum), security (tZERO), international remittance, arts and photography (Kodak, based on KodakOne and KodakCoin), and more.¹⁶

However, there are blockchain platforms that do not need circulation of cryptocurrencies as the medium of

¹³Technically speaking, the language for the scripts in Ethereum transactions is Turing-complete, a class of language that allows complex statements. This capacity of allowing complexity makes state-contingent contracts possible.

¹⁴See Buterin (2016) for more details.

¹⁵We can also think of θ to represent how precisely the consensus over the distributed ledger works.

¹⁶Another interesting example of using distributed ledgers is Ripple. Although the underlying technology is not exactly the blockchain, Ripple also utilizes the distributed ledger to provide secure transactions between banks and commercial firms, in which the cryptocurrency (XRP) is used. The approval of transaction is not made by PoW as in Bitcoin, but by a certified set of validating nodes. Hence the waiting time of transaction and waste of electricity inherent in PoW system do not apply.

transactions. For instance, Hyperledger, providing the blockchain platforms for exchanging a variety of assets (wine, arts, jewelry), claims that they have no interest in building their own cryptocurrency to avoid many political challenges.¹⁷ Moreover, a number of permissioned blockchain platforms¹⁸ do not need to use the digital currency or mining process to record the information. For the blockchain platforms whose transactions are not necessarily executed by cryptocurrency, the model provides an implication for the fundamental value (price) of the blockchain itself. Specifically, in Section 5., our model proposes the theoretical measure for the price of these type of blockchain technology, and show that it corresponds to the welfare gain of participants in the network.

3. Theoretical Framework

Consider an economy with segmented markets that operate at t = 0 and 1. There is a continuum of riskneutral consumers (traders) characterized by the productivity α . The random productivity has a cumulative measure $F : [0,1] \rightarrow [0,1]$, which will be assumed to be uniform later. At date t = 0, each trader is endowed with a certain amount of cash w, draws the productivity α , and partakes in markets to buy an asset. They consume only at the end of t = 1. In Subsection 3.1., buyers' equilibrium is analyzed under the fixed asset supply in each market: we make it endogenous variable in the analysis of general equilibrium in Section 3.2.

Besides a risk free saving facility, two types of assets are traded: low-quality and high-quality. The quality type is denoted by $q \in \{L, H\}$, and the asset is used to start a project which yields the following (per capita) return at date t = 1:

$$y(\alpha) = \begin{cases} \alpha & \text{if } q = H \\ \phi \alpha & \text{if } q = L, \end{cases}$$

where $\phi \in (0, 1)$ is the primitive quality difference. If the asset is low-quality, consumers obtain only ϕ fraction of return from the investment project. Note that the use of the terms "asset" and "return" has no implications for the type of assets traded: we can also think of it as "consumption goods" that yield some "private values (utility)" as in Parlour (1998). Following the literature on market microstructure (such as Glosten and Milgrom, 1985), agents can trade at most one unit of asset and cannot short sale.

There are two different trading platforms. Orders submitted into each platform have to be settled in a different medium of exchange. One is the cryptocurrency and the other is the fiat money. We give transactions with cryptocurrency an index j = B (blockchain) and that with fiat money an index j = C (cash).

3.1. Cryptocurrency Pricing with Exogenous Supply and Quality

Throughout this subsection, we assume the following assumptions. First, the amount of asset supply in each market is given by K_j^S , $j \in \{B, C\}$. Also, the share of the high-quality assets in market-j is denoted by $\pi_j \equiv \Pr(q_j = H)$. Moreover, to motivate the choice of trading venues, we consider following assumptions.

Assumption 1. The transactions with cryptocurrency incur a lower risk of counterfeit, *i.e.*, $\pi_B > \pi_C$.

Assumption 2. If a trader intends to buy *d* amount of assets at price *P* in *B*-market, she has to hold *Pd* of cryptocurrency to purchase the asset.

¹⁷http://www.eweek.com/cloud/hyperledger-blockchain-project-is-not-about-bitcoin

¹⁸Users of blockchains can make the network private and limit the information transaction within a firm or a group of firms. This category of platforms is called "closed-type" or "permissioned" blockchain. The public blockchain, in contrast, is called "open-type" or "permissionless" blockchain. The possible effects of these degrees of transparency on the trading behavior under the private blockchain are analyzed by Malinova and Park (2017).

The first assumption reflects the secure nature of blockchain. The fixed supply K_j and share of non-lemons π_j , as well as Assumption 1 will be relaxed and derived as endogenous consequences of the optimal behavior of asset suppliers in subsection 3.2. Specifically, we will see that the tamper-proof nature and state-contingency of transactions on blockchain make high-quality assets cluster in *B*-market, that is, one market endogenously attracts disproportional amounts of a particular type of asset. In the language of θ , we can interpret $\theta = \pi_B - \pi_C$. The second assumption comes from the fact that the endowment is given by cash and called "cryptocurrency in advance (CIA)" constraint.¹⁹ It will be clear that the demand and pricing for cryptocurrency are determined mostly outside of the asset trading market. Therefore, by removing Assumption 2 and imposing it on sellers' behavior, we can also analyze the other class of cryptocurrency platforms, such as a part of Ethereum, in which the sellers need to have cryptocurrency to verify their authenticity. Also, we show in Section 5. that the fundamental price of blockchain technology is characterized even without the circulation of cryptocurrency.

Optimal Behavior of Buyers

A buyer with type α maximizes her expected consumption $E[c]\alpha$ under the following budget constraints:

$$w = P_C k_C + Qb + s, \ Qb \ge P_B k_B,$$

$$c = y_C(\alpha)k_C + y_B(\alpha)k_B + s.$$

 k_j and P_j represent the demand and price of capital at market-j, Q is the price of cryptocurrency, and b is the demand for cryptocurrency. The prices are denominated by numeraire. Thus, the price of assets traded in *B*-market in terms of cryptocurrency is P_B/Q . A risk-free saving is denoted by s.

The agent allocates her cash endowment to the purchase of the asset in *C*-market and cryptocurrency. She also uses the cryptocurrency to purchase the asset in *B*-market. Note that the amount of purchase in *B*-market is bounded from above by her holding of cryptocurrency as Assumption 2 suggests. It is also possible that the agent does not buy any assets and holds all the cash endowment as the risk-free saving, *i.e.*, she can stay inactive in the asset markets.

The productivity adjusted by the lemons' risk is

$$y_j(\alpha) = \tilde{\pi}_j \alpha = [\pi_j + (1 - \pi_j)\phi]\alpha, j \in \{C, B\}.$$

Because of the risk neutrality and linearity of y, splitting order into two markets is not optimal. Thus, the demand always hits its upper limit, *i.e.*, $k_j = 1$ and CIA constraint except for mass-zero buyers. Therefore, the return from purchasing asset in each market and that from staying inactive are given by

$$V_{C} = \tilde{\pi}_{C} \alpha - P_{C},$$
$$V_{B} = \tilde{\pi}_{B} \alpha - P_{B},$$
$$V_{0} = 0.$$

Note that we subtract *w* from equations above because it does not affect the equilibrium behavior.

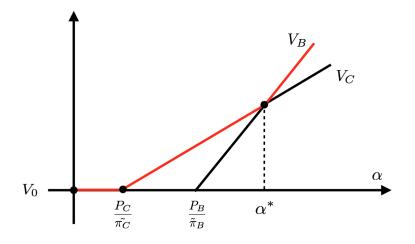
To solve the venue choice problem, we focus on the following equilibrium:

$$\frac{P_B}{\tilde{\pi}_B} > \frac{P_C}{\tilde{\pi}_C},\tag{1}$$

¹⁹As explained in the introduction, this assumption captures the class of cryptocurrencies that are used as a mean of exchange in the blockchain trading platform. The analyses in Section 5. provide the measure for the fundamental value of blockchain, instead of the value of the cryptocurrency, and it does not need this assumption regarding CIA.

which will be shown to be a unique equilibrium. Intuitively, $P_j/\tilde{\pi}_j$ represents the cutoff of the productivity that makes it indifferent between buying an asset in *j*-market and staying inactive. The inequality (1), together with $\tilde{\pi}_B > \tilde{\pi}_C$, indicates that there is a positive measure of traders with relatively high α who wish to go to *B*-market.

Figure 3: Returns for Buyers



Indeed, under (1), the optimal behavior of buyer with type- α is determined by the cutoff α^* such that

$$\alpha^* \equiv \frac{P_B - P_C}{\tilde{\pi}_B - \tilde{\pi}_C}.$$

Fig.3 plots returns, V_i , against α and shows the cutoffs for the optimal behavior. Namely, it is optimal for type- α trades to (i) buy one unit of asset in *B*-market if $\alpha \ge \alpha^*$, (ii) in *C*-market if $\alpha \in [\frac{P_C}{\pi_C}, \alpha^*)$, and (iii) stay inactive otherwise. Intuitively, each buyer faces the tradeoff between price and quality, *i.e.*, *B*-market provides higher quality and expected return, while it charges a higher price. When α is sufficiently high, the gain from the high average quality in *B*-market outweighs the price cost, making buyers purchase in *B*-market.

By aggregating along α , the total demand in each market is

$$K_B^D = 1 - F(\alpha^*), \tag{2}$$

$$K_C^D = F(\alpha^*) - F\left(\frac{P_C}{\tilde{\pi}_C}\right).$$
(3)

We assume that Frepresents uniform distribution. Thus, inverse demand functions can be derived as follows.

$$P_{C} = \left(\frac{1}{\tilde{\pi}_{C}} + \frac{1}{\Delta\tilde{\pi}}\right)^{-1} \left(\frac{P_{B}}{\Delta\tilde{\pi}} - K_{C}^{D}\right),\tag{4}$$

$$P_B = P_C + \Delta \tilde{\pi} (1 - K_B^D), \tag{5}$$

with $\Delta \tilde{\pi} = \tilde{\pi}_B - \tilde{\pi}_C$. Note that plugging $K_j^S = K_j^D$ yields the equilibrium prices.

The price in one market affects the price in the other market: there is a complementarity across them. When P_B increases, not only does it dampen the demand in *B*-market, but it also increases the demand in *C*-market because marginal traders migrate from *B*-market to *C*-market. This is true for the change in P_C too, but it also generates the switch of the marginal traders between active and inactive. Also, the quality difference (also

referred to as quality spread), $\Delta \tilde{\pi}$, affects the prices in opposite ways. A larger quality difference induces more traders to migrate from *C*-market to *B*-market, leading to a lower P_C and higher P_B . To grasp intuitions, we can also look at the price difference (also referred to as price spread), $P_B - P_C$, which stems from the quality difference multiplied by $1 - K_B$. This can be seen as a premium: the asset in *B*-market obtains a higher valuation than the one in *C*-market by its higher quality, $\Delta \tilde{\pi}$, but it has an effect through, $1 - K_B$, because the change in $\Delta \tilde{\pi}$ increases the demand in *B*-market by making traders who have not traded in *B*-market migrate to *B*-market.

The last market to be cleared is the one for the cryptocurrency. The total demand for cryptocurrency is given by

$$QB_D = P_B \int k_B dF = P_B K_B$$
$$= P_B (1 - F(\alpha^*)).$$

The market clearing condition for the cryptocurrency market, given the supply B_S , is

$$B_D = \frac{P_B}{Q}(1 - F(\alpha^*)) = B_S,$$

which yields

$$Q = \frac{P_B}{B_S} (1 - F(\alpha^*))$$

= $\frac{K_B^S}{B_S} [\tilde{\pi}_B (1 - K) + \Delta \tilde{\pi} K_C^S].$ (6)

The price of cryptocurrency is increasing in (i) the total transaction in market-*B*, (ii) the quality level in market-*B* (π_b), and (iii) the quality difference between two markets $\Delta \pi$. The first and second effects have direct implications because both increase the demand in *B*-market. As for the third effect, a larger difference in the quality makes traders in *C*-market migrate to *B*-market, boosting the demand in *B*-market. Note that this effect is multiplied by K_C^S since it occurs by affecting the traders initially attempted to trade in *C*-market, those who have a measure K_C^S . The supply of cryptocurrency B_S negatively affects *Q* through the traditional demand-supply effect. Finally, it is routine to verify that (1) holds in this equilibrium.

3.2. Endogenous Supply and Quality

This subsection makes the supply and quality endogenous, while keeping the secure nature of cryptocurrency salient enough. For this purpose, we relax Assumption 1 as follows.

Assumption 1' θ fraction of low-quality assets that sellers intend to sell in *B*-market are detected and rejected by the blockchain.

The parameter $\theta \in (0, 1)$ can be a metric to measure the security of the blockchain. As explained in Section 2., interpretations of θ can be different depending on into what kind of context we apply this model. For instance, if the traded asset is the cryptocurrency itself, such as Bitcoin, θ is the probability that attempted "double spending" is precluded by the mechanism. If the traded asset is consumption goods, as in Wine blockchain, θ captures the quality of the scripts that describe the conditions on which the contracts are made

contingent.²⁰

Suppose that the sell-side of the market has a similar structure as the one for buyers. There is a continuum of sellers. Each agent has a productivity (or private value) $\alpha \sim F = U : [0, 1] \rightarrow [0, 1]$, and endowed with one unit of asset with quality q such that

$$\Pr(q = H) = \pi \in (0, 1).$$

Therefore, by the law of large number, the economy-wide fraction of the high-quality is π , and that of the low-quality asset is $1 - \pi$.

We also assume that each seller knows the quality of her own asset. This information structure can be generalized by assuming that the seller is informed with probability λ and uninformed with probability $1 - \lambda$. If one is informed, she knows a specific characteristic of the asset and can distinguish lemons, while uninformed agents cannot tell the difference.²¹ We provide the analyses in the generalized case in Appendix A. It is worth mentioning that each seller does not engage in strategic trading: the signaling effect of venue-choice is shunted aside because each trader is non-atomic. Instead, we show that the sell-side selection (screening) occurs due to $\theta > 0$ even in the competitive equilibrium.²²

To solve for the optimal behavior, we guess (1) again. Note that (1) and $\pi_B > \pi_C$ imply

$$P_B > P_C$$

It will be shown later that these two conditions hold in equilibrium.

Optimal Behavior of Sellers

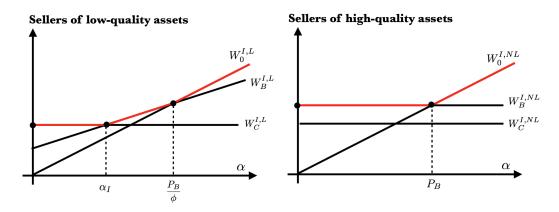


Figure 4: Returns for Informed Sellers

First, we consider the optimal strategy of informed sellers with low-quality assets. If she sells it in *B*-market, the expected return is $W_B^{I,L} = (1 - \theta)P_B + \theta\phi\alpha$. The first term is the case where the transaction avoids rejection, while the second term is the case where the asset is rejected by the blockchain. In the latter case, she must use the asset to invest in her own project to get $\phi\alpha$. If she sold it in *C*-market, the return is $W_C^{I,L} = P_C$,

²⁰Another interpretation of θ is in light of consensus quality in Cong and He (2017). Although the distributed ledger makes consensus to the state close to perfect by aggregating the reports by system keepers, there is still noise and bias in the consensus. We take large θ as precise consensus.

²¹In this case, assume, for simplicity, that the realization of α is independent of the realization of being informed or uninformed.

²²Notice that, by setting the model in this way, we also implicitly exclude the possibility of collusion by sellers as in Cong and He (2017). Since sellers are non-atomic, each of their behavior does not impact either of the market prices, quantity, nor quality. Therefore, there is no way of collusion by sellers.

while the return from staying inactive is $W_0^{I,L} = \phi \alpha$. See the left panel of Fig.4 for the diagram of these value functions.

By comparing these three returns as functions of α under $P_B > P_C$, the optimal strategy is to (i) stay inactive if $\alpha > \frac{P_B}{\phi}$, (ii) sell it in *B*-market if $\alpha \in (\alpha_I, \frac{P_B}{\phi}]$, and (iii) sell it in *C*-market if $\alpha \le \alpha_I$, where

$$\alpha_I = \max\left\{\frac{P_C - (1 - \theta)P_B}{\phi\theta}, 0\right\}$$
(7)

is the cutoff that separates sellers in *B*-market and *C*-market. As a result, informed traders split lemons into two markets at the aggregate level. When it is strictly positive, the cutoff, α_I , increasing in θ , decreasing in ϕ , and increasing in the expected price difference (numerator of α_I). Note that α_I represents the threshold between selling in *B*- and *C*-markets. An increase in θ makes sellers who traded in *B*-market migrate to *C*-market because a higher rejection probability lowers their expected profit. On the other hand, a higher ϕ increases the profit from selling in *B*-market. This makes marginal sellers switch to sell in *B*-market. Finally, a larger difference in the expected prices, $P_C - (1 - \theta)P_B$ makes *C*-market more attractive.

Note that sellers with high- α are more likely to sell lemons in *B*-market, while low- α sellers tend to go to *C*-market. This selection is the natural consequence of the price-liquidity tradeoff, *i.e.*, *B*-market provides a higher selling price but there is a risk of detection. Sellers with high- α do not care about the lower execution probability in *B*-market because they can produce relatively high output $\phi \alpha$ even if selling order is rejected. The opposite is true for low- α sellers: they dislike the execution risk in *B*-market and prefer *C*-market because they cannot derive a high continuation value from the asset.

If an informed seller has a high-quality asset, the return from selling it in C-market, *B*-market, and that from holding it are given by²³

$$W_C^{I,N} = P_C,$$

$$W_B^{I,N} = P_B,$$

$$W_0^{I,N} = \alpha.$$

Under $P_B > P_C$, the optimal behavior of sellers with high-quality assets is to (i) stay inactive if $\alpha > P_B$ and (ii) sells it in B-market if $\alpha \le P_B$. The right panel of Fig.4 shows the comparison.

Therefore, the amount of assets informed sellers intend to sell in each market is

$$S_B^I = \pi F(P_B) + (1 - \pi) \left[F\left(\frac{P_B}{\phi}\right) - F\left(\alpha_I\right) \right], \tag{8}$$

$$S_C^I = (1 - \pi) F(\alpha_I).$$
⁽⁹⁾

In (8), the first term is the supply from non-lemons holders, and the second term is the one from lemons holders. (9) only consists of the selling behavior of lemons holders. As suggested by the literature on adverse selection with segmented markets (Chen, 2012; Kim, 2012; Guerrieri and Shimer, 2014; Chang, 2017), the market with a low (higher) price and deeper (shallower) liquidity tends to attract low-quality (high-quality) assets because the different prices and liquidity can work as the screening device.

²³More precisely, a seller who sold the asset in *B*-market obtains P_B/Q of cryptocurrency, which amounts to P_B in terms of cash value. We implicitly assume that sellers have access to a dynamic market for the cryptocurrency, in which they can exchange cryptocurrency with fiat money at the same exchange rate Q over time. This assumption is motivated by the overlapping generations of traders. The structure of generations are identical over time, and buyers in their young period arrive at the markets and demand cryptocurrency as a mean of exchange. On the sell side, old sellers are ready to exchange their cryptocurrency with fiat money. Note that the term "generation" does not have any implications for the time-interval between trading. We can consider the dynamic change in the price driven by the growth in the population (transaction volume), change in the initial asset allocation, and size of the networks as a future extension.

Since the blockchain technology weeds out θ fraction of lemons from *B*-market, the supply functions from informed sellers are given by

$$K_B^I = \pi F(P_B) + (1 - \pi)(1 - \theta) \left[F\left(\frac{P_B}{\phi}\right) - F(\alpha_I) \right]$$

and $K_C^I = S_C^I$. As a result, the market quality in each market is derived as follows:

$$\pi_B = \frac{\pi F(P_B)}{\pi F(P_B) + (1 - \pi)(1 - \theta) \left[F\left(\frac{P_B}{\phi}\right) - F\left(\alpha_I\right) \right]}, \, \pi_C = 0.$$

Note that all of the high-quality assets go to *B*-market since it provides a higher price. In other words, all of the asset traded in *C*-market is of low-quality. This result comes from the information structure of sellers (i.e., all of them know the quality of their assets), and it is strained if we think about the real economy. In Appendix **A**, we redefine the equilibrium with uninformed sellers to show that a more general information structure provides $\pi_C > 0$ in the equilibrium.

Proposition 1. The blockchain market achieves a higher quality than the cash market, i.e., $\pi_B > \pi_C$.

Proof. See Appendix B1.

Proposition 3.2. has a direct implication for the prices. That is, the higher quality in *B*-market than *C*-market results in a higher price in *B*-market as well.

Proposition 2. The price of assets traded by cryptocurrency is higher than the price in the traditional cash market, that is, $P_B > P_C$.

Proof. See Appendix B1.

Note that these differences between two markets are implications of $\theta > 0$. The secure nature of blockchain has a power to sort low-quality asset out even in the general equilibrium. What should be underlined is the fact that informed sellers do not trade strategically. They do not incorporate the signaling effect of the choice of trading platforms because the behavior of each agent is nonatomic and does not affect the equilibrium quality π_j , as well as the behavior of buyers. Rather, the sell-side selection is a consequence of the purely competitive tradeoff between the higher equilibrium price in *B*-market and detection risk. Due to its higher continuation values, high-quality assets tend to cluster in *B*-market, while the low-quality assets cluster in *C*-market to avoid the transaction failure in *B*-market. This mechanism generates the higher quality and price in *B*-market (spreads), which are self-sustaining in the equilibrium.

Definition. The general equilibrium is defined by the price, quality, and quantity, $(Q, \{P_j, \pi_j, K_j\}_{j \in \{C,B\}})$ that solve the equations (4), (5), (6), (23), and (24), where $\{K_i^S\}_{j \in \{C,B\}}$ are given by (22) and (21).

We can easily derive the equilibrium price, quality, and quantity traded when the economy has a single cash market (no blockchain market).

Corollary 1. In the economy with a single (cash) market, the equilibrium is given by

$$\begin{split} K^D_{\rm C} &= 1 - \frac{P_{\rm C}}{\pi_{\rm C}}, K^S_{\rm C} = \lambda [\pi P_{\rm C} + 1 - \pi] + (1 - \lambda) \frac{P_{\rm C}}{\phi}, \\ \pi_{\rm C} &= \frac{\lambda P_{\rm C} + (1 - \lambda) \frac{P_{\rm C}}{\phi}}{\lambda [\pi P_{\rm C} + 1 - \pi] + (1 - \lambda) \frac{P_{\rm C}}{\phi}} \pi, \end{split}$$

where λ is the fraction of informed sellers.

As we can see from equations above, the economy is not continuous at $\theta = 0$. When we make $\theta \searrow 0$, the economy approaches to the segmented markets economy with two homogeneous markets, while the economy in Corollary 3.2. has only one market. Therefore, there is a structural break at $\theta = 0$. For this reason, we do not compare the single market economy with segmented markets economy.²⁴ Rather, we focus on the comparative statics in the segmented markets.

4. Comparative Statics in the Benchmark Model

Even though the model is simple, its solution is non-linear and turns out complex to conduct comparative statics. Therefore, we analyze the simplified benchmark model with $\lambda = 1$, *i.e.*, there are no uninformed sellers (as in most of the literature on adverse selection). We provide numerical solution for the economy with $\lambda < 1$ in Appendix A. For a technical reason, assume that the primitives of the economy satisfy the following condition:²⁵ $\pi(1-\pi)(1-\phi) < 1/4$.

4.1. Effect of Security Improvement

In this economy, the key parameter that allows cryptocurrency to circulate is θ . Specifically, the effects of a higher security (represented by a higher θ) on the price of cryptocurrency and quality of the markets will be our first concern. With $\lambda = 1$, we have $\pi_C = 0$, and the equilibrium (under the normalization of $B_S = 1$) is given by solving the following equations:

$$K_{C}^{S} = (1 - \pi)\alpha_{I}, K_{B}^{S} = \pi P_{B} + (1 - \pi)(1 - \theta)\left(\frac{P_{B}}{\phi} - \alpha_{I}\right),$$

$$K_{B}^{D} = 1 - \frac{P_{B} - P_{C}}{\tilde{\pi}_{B} - \phi}, K_{C}^{D} = \frac{P_{B} - P_{C}}{\tilde{\pi}_{B} - \phi} - \frac{P_{C}}{\phi},$$

$$\pi_{B} = \frac{\pi P_{B}}{K_{B}},$$

$$Q = P_{B}K_{B}^{i}.$$
(10)

*K*s in the first and second lines are the supply and demand in both market, and the quality in *B*-market is given by the third line. The equilibrium switches when θ becomes too low to sustain $\alpha_I = P_C - (1 - \theta)P_B > 0$.

Proposition 3. Let θ_0 be the smaller solution of $0 = \theta^2(1 - \pi) - \theta + \pi(1 - \phi)$. α_I is positive if and only if $\theta > \theta_0$.

Proof. See Appendix B2.

This result implies that *C*-market shuts down ($\alpha_I = 0$) when θ is sufficiently small. This market break down comes from the behavior on the supply side. Remember only *L*-assets holders supply into *C*-market. They wish to sell the asset at a higher price P_B but they face the tradeoff between the price-improvement and rejection risk in *B*-market. When θ is sufficiently small, the rejection risk becomes sufficiently small so that the price improvement in *B*-market becomes dominant. As a result, all of these sellers migrate out of *C*-market and supply in *B*-market.

Of course, it is not realistic that the cash-market breaks down, and we can avoid it by either considering the general model with $\lambda < 1$, or restrict our focus on $\theta \ge \theta_0$. In this section, we keep $\lambda = 1$ and let θ sufficiently high, as the blockchain in the real world suggests (discussions with $\theta \le \theta_0$ are given in Appendix B2.).

²⁴We can analyze the right-limit, $\theta \searrow 0$, of the segmented markets economy but it is out of the focus of this paper since, in the homogeneous markets economy, the behavior of traders completely depends on the belief on the behavior of other agents.

²⁵This condition guarantees that the economy has both cases of $\alpha_I > 0$ and $\alpha_I = 0$.

Assume $\theta > \theta_0$. Then the equilibrium solves equations in (10). By using $K_B^D + K_C^D = 1 - P_C/\phi$, and equating $K_i^D = K_i^S$, we obtain

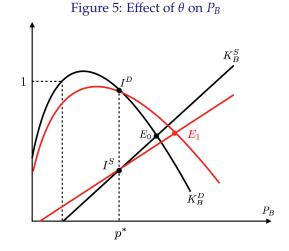
$$P_{C} = \frac{\phi}{2 - \pi} (1 - \pi P_{B}). \tag{12}$$

Thus, the prices in two markets are negatively related. Suppose that there is a positive shift in P_B in the equilibrium. This is an indicator of changes in some parameters that cause a positive excess demand in *B*-market. In the parallel markets economy, a larger demand-supply gap in one market occurs with a non-positive demand-supply relationship in the other market. Hence, the higher P_B happens at the expense of a lower P_C in the equilibrium.

Also, by using the expression for π_B in (29), we derive the demand and supply function in *B*-market:

$$K_B^S = P_B \left[\pi + \frac{(1-\pi)(1-\theta)}{\phi \theta} \left(1 + \frac{\phi \pi}{2-\pi} \right) \right] - \frac{(1-\pi)(1-\theta)}{\theta(2-\pi)},\tag{13}$$

$$K_B^D = 1 - \frac{\left(1 + \frac{\phi\pi}{2-\pi}\right)P_B - \frac{\phi}{2-\pi}}{(1-\phi)\pi P_B}K_B^S.$$
(14)



Note that, given P_B , there is a strategic substitution between demand and supply in (14). When we fix P_B , a larger supply in *B*-market must come from an increase in the supply of low-quality assets,²⁶ which dilutes the share of *H*-asset in *B*-market. This lowers π_B and makes buyers less willing to buy, leading to a fewer demand K_B^D . Of course, this happens alongside with the adjustment by P_B , and the resulting effect is not straightforward.

Consider an increase in the detective power of blockchain (a higher θ). As Figure 5 suggests, this pushes up the supply when P_B is small, while it shifts the supply downward when P_B is large. It can be shown that there is p^* such that $P_B \ge p^* \Leftrightarrow P_B \ge P_C$, and we can focus on $P_B > p^*$ (see Appendix B for the explicit form of p^*).

When θ increases, the supply of high-quality asset is not directly affected, as in (10). Therefore, a higher θ reduces the supply of low-quality asset in *B*-market, as long as there is a positive supply of low-quality assets, *i.e.*, $P_B > P_C$. Thus, when P_B is sufficiently large (and this is the equilibrium), (i) a higher θ reduces K_B^S by detecting and sweeping out low-quality assets.²⁷ It is obvious that (ii) this improves the *B*-market's quality,

²⁶Recall that the supply of high-quality asset is determined by comparing P_B , P_C , and α , and none of them are affected directly by θ .

²⁷When $P_B < P_C$, sellers with L-asset either sell it in C-market or keep it to produce $\phi \alpha$. This case has no economic implications since the

i.e., π_B increases. Then, as the strategic substitution (with fixed P_B) works, (iii) buyers are more willing to buy in *B*-market, causing a higher equilibrium price P_B .

The effect on π_B is more complicated. First, as explained above, the direct effects, (i) and (ii), on π_B are positive. On the other hand, we have a higher price P_B through the effect (iii) in equilibrium. This strengthens the incentive for sellers, both with high- and low-quality assets, to supply in *B*-market. A larger supply of high-quality asset obviously has a positive effect on π_B , while the effect of low-quality asset is negative. This negative effect is, however, muted by the higher detection probability θ , and π_B increases.

Overall, we have the following results:

Proposition 4. The segmented market economy admits a unique solution, in which a higher θ has a positive impact on P_B and π_B and a negative impact on P_C .

Proof. See Appendix B4.

4.2. Non-linear Effect on the Price of Cryptocurrency

Finally, we shed light on the effect of higher security on the price of cryptocurrency, Q. It sounds natural that a stronger blockchain with a more secure mechanism (high- θ) increases the price of cryptocurrency by attracting a larger demand for the transaction in *B*-market and inducing a larger demand for cryptocurrency as a mean of exchange. However, it turns out this is not always true: our model shows a higher θ is more likely to lower the demand for cryptocurrency and its price when the adverse selection is not severe, or the level of θ is sufficiently small.

Formally, the benchmark with $\lambda = 1$ and $\theta > \theta_0$ provides the following proposition. To state it, define the value of ϕ that separates the behavior of Q: let $\phi_1 = \frac{2-\pi}{3-\pi}$, and $\phi_0(<\phi_1)$ be the unique solution of (38) in Appendix B4..

Proposition 5. (i) If $\phi < \phi_0$, *Q* is monotonically increasing in θ . (ii) If $\phi_0 \le \phi < \phi_1$, *Q* takes *U*-shaped curve, and there is θ^* s.t.,

$$\frac{dQ}{d\theta} \le 0 \Leftrightarrow \theta \le \theta^*.$$

(iii) If $\phi_1 \leq \phi \leq 1$, *Q* is monotonically decreasing in θ .

Proof. See Appendix B4. It also provides the critical value for ϕ .

To separate the intuition, rewrite the pricing equation of cryptocurrency:

$$Q = P_B K_B$$

where we set $B_S = 1$ since this makes no differences in our analyses.

First, when θ increases, we found that a more secure blockchain technology tends to widen both price and quality spreads, ΔP and $\Delta \pi$. The former reduces the demand in *B*-market, while the latter increases it. We can interpret this result by thinking *B*-market as "the exclusive market only for highly qualified products." Of course, this type of markets charges a higher price. Second, the formula of *Q* implies that it increases when P_B increases more than K_B declines. Together with these effects, we have to keep in mind that the buyers' venue choice is driven by the difference between high- and low-quality assets (ϕ), the price spread (ΔP), and the quality spread ($\Delta \pi$). More precisely, the result depends on how easy buyers can migrate to *C*-market to avoid a higher P_B .

equation implies there is a demand from sellers. The arguments and figure consist this case to make the mathematical analysis globally consistent.

When ϕ is sufficiently large, the value of *L*-asset is high, which means a less severe adverse selection problem, *i.e.*, the difference between two types is small. In such an economy, buyers are not very eager to have *H*-assets and not attracted to a higher π_B in *B*-market. Hence, the cost of changing the platform from *B* to *C*-market is small. As a result, *P*_B does not increase much because the price elasticity of demand is high, *i.e.*, a higher price induced by a higher θ is more likely to dampen the incentive to buy in *B*-market. Since the increase in *P*_B is not large compared to the decline in *K*_B the price of the cryptocurrency declines.

On the other hand, buyers can be more attracted to a higher quality in *B*-market when the value of *L*-asset, ϕ , is small. In this case, the difference between *H*-asset and *L*-asset is significant in terms of ϕ . However, if θ is sufficiently small, then the quality level π_B , as well as the difference between two markets, $\Delta \pi$, are small. That is, the difference in buying in *B*-market and *C*-market is not significant in terms of the probability of purchasing low-quality assets. In this situation, a marginal increase in θ makes buyers in *B*-market migrate away to *C*-market, since *C*-market provides a lower price (recall P_C is negatively correlated with P_B) while the difference in π_j is relatively small. This leads to the decline in the transaction demand in *B*-market more than the increase in P_B , lowering the price Q. If θ is large, *B*-market provides a significantly larger number of high-quality of assets, *i.e.*, the difference between π_B and π_C becomes large. Therefore, even if the price increases in *B*-market, only a few buyers migrate to *C*-market because a higher average quality in *B*-market is irreplaceable by *C*-market. This results in the small decline in K_B compared to the increase in P_B , leading to a larger demand for the cryptocurrency.

The key message here is that the "structure" of the markets is an important factor. It is well understood from Akerlof (1970) and subsequent studies that the existence of lemons and asymmetric information hamper the economic activity. Our parsimonious model suggests that the different market structures, such as the segmented markets operated in parallel—yet with different levels of tamper-proofness θ —can be the other important sources of market inefficiency.²⁸ Specifically, it demonstrates that having the second market operated alongside with the cash market, and changing the structure of it, can affect the transaction, price, and market quality of the first traditional cash market.

5. Welfare Analyses: Fundamental Value of Blockchain

In this section, we calculate the aggregate welfare of buyers and sellers, as well as the gain of welfare due to the introduction of blockchain technology. As the CIA constraint always binds, the welfare comparison does not hinge on the existence of cryptocurrency (CIA constraint). More generally, the equilibrium variables with and without the CIA constraint are identical except *Q*. Due to this identity, we can apply the discussion in this section to the class of the blockchain platforms that do not rely on the circulation of cryptocurrency.²⁹ We first consider buyers' perspective and move on to the sellers' one.

5.1. Welfare of Buyers

We define the aggregate welfare of buyers by integrating the gain from trade (we ignore the common constant endowment *w*):

$$v_B = \int_{\alpha^*} (\tilde{\pi}_B \alpha - P_B) dF + \int_{P_C/\phi}^{\alpha^*} (\phi \alpha - P_C) dF$$
(15)

$$= \int_{\alpha^*} (\Delta \tilde{\pi} \alpha - \Delta P) dF + \int_{P_C/\phi} (\phi \alpha - P_C) dF$$
(16)

²⁸The meaning of "efficiency" hinges on the welfare of traders, which is analyzed in Section 5..

 $^{^{29}}$ See Section 2. for the real-world examples.

In (15), the first term is the welfare of buyers who purchase in *B*-market, and the second term is the one of traders who purchase in *C*-market. This can be rewritten in terms of "gain" as in (16). The second term of (16) represents the welfare of all the active buyers from purchasing in *C*-market, *i.e.*, the reservation welfare when agents can use only *C*-market. The first term of (16) is the gain (increment) of welfare that stems from changing the trading platform from *C* to *B*-market, which only $\alpha \ge \alpha^*$ agents attempt to do.

The innovation in the security level of the blockchain, θ , has the following impact on v_B .

Proposition 6. (i) When $\pi > 1/2$, v_B is monotonically increasing in θ .

(ii) When $\pi \leq 1/2$, there is a unique ϕ_2 . If $\phi < \phi_2$, then v_B is monotonically increasing in θ . Otherwise, there is a unique $\theta^{**} \in (0, 1]$ such that

$$\frac{dv_B}{d\theta} \ge 0 \Leftrightarrow \theta \ge \theta^{**}.$$

Proof. See Appendix C.

Together with Q, the behavior of buyers' welfare also has a U-shaped trajectory for a certain set of parameters. Once again, this result comes from buyers' tradeoff between price and quality. When θ is small, the quality difference, $\Delta \pi$, is not so large, while the additional improvement of θ leads to a higher price in B-market. Since the cost of changing the trading venues is small, trading volume in B-market declines more than the increment in P_B . This implies that the additional improvement in θ reduces the total gain of welfare for buyers who trade in B-market, which is the first term of (16), because the trading in B-market becomes less active in terms of the transaction value. Of course, a decline in P_C increases the reservation welfare (the second term of (16)). However, the decline in P_C is not so large (or P_C can even increase) due to the migration of buyers from B to C-market, which (partially) cancels out the first round negative effect of θ on K_C^D . Thus, the first effect tends to dominate the second effect.

When θ is high, on the other hand, the quality difference between two markets is significant. In this case, a higher P_B caused by the innovation does not reduce the demand in *B*-market since it is too costly for a buyer to change the platform. Thus the opposite arguments to the low- θ case apply, and the innovation in the blockchain improves the welfare of buyers.

Proposition 5.1. is interesting in its dependence on π . When π is relatively high, it may seem natural to say that the increase in θ reduces the demand in *B*-market and welfare gain of buyers more, because the higher fraction of high-quality assets makes it easy to migrate away to *C*-market. This is not true in this model because what matters for buyers is not the economic-wide share of the high-quality assets, but its market share and how it is affected by the increase in θ .

When π is large enough, the marginal increase in the fraction of asset rejected by the blockchain, $(1 - \pi)\theta$, becomes small. That is, the innovation does not cause the large quality improvement nor the huge reduction of K_B^S . Because of that, the increment in P_B caused by the higher θ is not significant enough to confound the demand in *B*-market. As a result of this small increase in P_B , buyers are not so motivated to change the trading platforms, the decline in K_B becomes weak, and the welfare gain represented by the first term in (16) stays high.

Overall, the innovation of the blockchain technology can be welfare improving if the underlying fraction of the high-quality assets is large or the adverse selection (measured by ϕ) is less severe. If the economy has a greater fraction of the low-quality assets, which is significantly bad compared to the high-quality one, and the quality spread is large across the markets, then the innovation in the blockchain reduces the buyers' welfare.

5.2. Fundamental Value of Blockchain Technology

In this subsection, we show that the access to the blockchain technology obtains a positive fundamental price. To see this, we introduce a blockchain manager, who maintains the blockchain platform, provides the blockchain service, and determines the level of θ (possibly by exerting some effort). The existence of this type of agent is realistic: even though the distributed ledger is managed by the participants of the blockchain network, there is an institution that provides the platform itself, e.g., Ethereum, Ripple and other examples provided in Section 2.

Let us introduce a pre-trade period t = -1. Formally, suppose that a randomly picked buyer is approached by the blockchain manager who charges a fee f for the access to B-market before the type α is drawn at t = 0.30Note that the behavior of this particular agent does not affect the expected market result because she is nonatomic. There is no bargaining and the offer is take-it-or-leave-it.

If she declines the contract, her expected welfare is

$$v_0 = \int_{\frac{P_C}{\phi}} (\phi \alpha - P_C) dF,$$

while the access to the blockchain technology provides the welfare (after the fee) of $v_B - f$. Thus, the level of the fee that makes her indifferent is³¹

$$f = v_B - v_0$$

= $\int_{\alpha^*} (\tilde{\pi}_B \alpha - P_B) dF + \int_{P_C/\phi}^{\alpha^*} (\phi \alpha - P_C) dF - \int_{P_C/\phi} (\phi \alpha - P_C) dF$
= $\int_{\alpha^*} (\Delta \tilde{\pi} \alpha - \Delta P) dF.$ (17)

In other words, the blockchain manager can charge the fee up to the amount of welfare gain given by (17). We can see this amount as the "price" of the blockchain technology or blockchain platform. Moreover, we have the following intuitive result.

Proposition 7. The fundamental price of blockchain is perfectly correlated with the price of cryptocurrency *Q* in the economy with CIA as following.

$$f = \int_{\alpha^*} (\Delta \tilde{\pi} \alpha - \Delta P) dF = \frac{\phi(1-\pi)}{2} Q.$$
 (18)

Proof. See equation (39) in Appendix C.

Collorary 2. The effect of innovation in the blockchain technology has the impact on the price of blockchain as proposed by Proposition 4.2..

This proposition suggests that, if the blockchain is accompanied by the cryptocurrency, then the fundamental value of the blockchain technology is perfectly measurable by the fundamental price of cryptocurrency. When the adverse selection is severe (ϕ is low) or the economic-wide share of the low-quality asset is small (π is large), then the price of cryptocurrency magnifies the fundamental value of the blockchain technology or the welfare gain for buyers (and vice versa).

³⁰One of the other ways to think about the price of blockchain is to charging f contingent on the usage of *B*-market. In this case, the profit of buying in *B*-market is shifted down by f only if a trader decides to trade in *B*-market. This formulation, however, ends up with complicated equilibrium formulas because it changes the cutoff of each trader. To abstract away from the complication, we focus on the setting in the main text.

 $^{^{31}}$ We assume the tie-break rule so that an agent accepts the contract with blockchain manager if she is indifferent.

Intuition behind the corollary 5.2. is identical to that of Proposition 4.2.. Whether the marginally higher security, θ , increases the fundamental value of the blockchain technology depends on the severity of adverse selection and the level of θ , because those factors determine the quality difference across two markets and how easy the migration will be.

Even though we do not analyze the connection between these two prices when the CIA constraint or the fee is imposed on the sellers' budget, the primary intuitions are almost the same. This is because Q is determined by the transaction value in *B*-market (P_BK_B), and the fee is proportional to the welfare gain in *B*-market, which is, in turn, proportional to P_BK_B . The fact that the market must clear in the equilibrium ($K_B^D = K_B^S$) makes these two arguments symmetric regardless of which side of the economy has to burden the price of the access to *B*-market.

Now, the analyses above open the door to the question on the optimal level of θ . As we have seen, the propositions (as well as the discussion with $\theta \leq \theta_0$ in Corollary B2. in Appendix B2.) suggest that setting $\theta = \theta_0$ or $\theta = 1$ is optimal for the welfare of buyers. However, it is hard to determine the difference of $v_B(\theta = 1)$ and $v_B(\theta = \theta_0)$ due to its discontinuity at $\theta = \theta_0$. Also, considering the cost of adjusting θ will provide the interesting implications, since it generally makes a gap between the optimal θ for the blockchain manager and for buyers' welfare. Moreover, it is not clear the objective of our welfare optimization: should it maximize the welfare of only buyers? What kind of cost do the blockchain maintenance and innovation require? Due to the lack of data, it is hard to determine the form of the cost function, and we leave the further discussions for the future task.

5.3. Welfare of Sellers

The welfare of sellers hinges on the quality of assets they are allocated upon their arrival at the economy. The aggregate welfare of sellers of *H*-asset and that of sellers of *L*-asset are

$$v_{S,NL} = \int_{P_B} \alpha dF + \int^{P_B} P_B dF,$$

$$v_{S,L} = \int_{\frac{P_B}{\phi}} \phi \alpha dF + \int_{\alpha^I}^{\frac{P_B}{\phi}} ((1-\theta)P_B + \theta \phi \alpha)dF + \int^{\alpha^I} P_C dF.$$

The first and second terms, in both of $v_{S,NL}$ and $v_{S,L}$, are welfare of keepers and sellers in *B*-market respectively. The last term of $v_{S,L}$ comes from sellers of *L*-asset in *C*-market. We can check that $v_{S,NL}$ is monotonically increasing in θ reflecting the higher price and revenue for high-quality assets holders. The effect of θ on $v_{S,L}$ is hard to determine, though we can obtain intuitions by analyzing the following representation.

$$v_{S,L} = P_C + \int_{\alpha^I}^1 ((1-\theta)P_B - P_C + \theta\phi\alpha)dF + \int_{\frac{P_B}{\phi}}^1 (1-\theta)(\phi\alpha - P_B)dF.$$
(19)

As in the case of buyers' welfare, we can separate it into the welfare gain parts and the reservation welfare. First, all the sellers certainly can obtain the reservation welfare of P_C by selling the asset in *C*-market (the first term in (19)). If $\alpha > \alpha_I$, the sellers change the behavior to either selling in *B*-market or keeping it. The second term in (19) represents the welfare gain of sellers from staying away from *C*-market: all of them ($\alpha > \alpha_I$) are better off by selling in *B*-market or keeping it. Within this subgroup, agents with relatively high α (such that $\alpha > \frac{P_B}{\phi}$) prefer to keep the asset by giving up the revenue P_B . This last component in the welfare gain is exhibited by the last term of $v_{S,L}$.

We can easily check that the first and last terms are monotonically decreasing in θ . That is, the reservation welfare (the first term) and the gain from changing behavior from selling in *C*-market to being keepers decline

as the blockchain market becomes more profitable. The sign of the impact on the middle term is affected by two competing effects. On one hand, a higher θ boots the revenue by heightening P_B . On the other hand, it reduces the expected revenue by making the rejection risk greater. The total effect depends on how large the positive welfare gain by the traders in *B*-market will be, and it is more likely to happen when the migration of buyers from *B*-market is not so large due to the severe adverse selection and large quality spread.

6. Empirical Implications

From the model we discussed in the previous sections, we can derive several empirical implications regarding the fundamental values of cryptocurrency and blockchain and their comparative statics. If we take the model with cryptocurrency with CIA constraint, we have the following empirical implications, even when it is difficult to measure the quality in each market. (i) The price in blockchain market is higher than the one in cash market (Proposition 3.2.). (ii) As the blockchain system develops and becomes secure, the price in blockchain market increases, while the price in the cash market decreases (Proposition 4.1.). (iii) As the blockchain system develops and becomes secure, depending on how bad the low quality good is, the price of cryptocurrency increases or decreases (Proposition 4.2.). If we have a dataset that contains the transaction price in the market where the transaction is made state-contingent due to blockchain technology and where the mean of transaction is cryptocurrency, then we can test the implication (i) by comparing the price to the one in the traditional market. In addition, if we have the data from the scratch of the transaction system, we can keep track of the price in blockchain market and the corresponding price in the traditional market to check the implication (ii).

The empirical implication (iii) is striking: the improvement in blockchain security system does not necessarily increase the demand for the cryptocurrency. Again, to understand this, the improvement in blockchain technology is on the supply-side. Although it improves the quality in blockchain market, it also raises the price in blockchain market. Therefore, the demand might decrease. If the effect of demand reduction dominates the effect of price increase, the demand for cryptocurrency decreases, which in turn decreases the fundamental price of cryptocurrency. Therefore, the improvement in security of blockchain does not have a robust testable implication as it has on blockchain market prices.

On the other hand, when we take into account the welfare results in Section 5., we have the following empirical implication. The value of the blockchain system is proportional to the fundamental price of cryptocurrency (Proposition 5.2.). This empirical implication has several applications. First, if we have a data that allows the measurement of the value of blockchain that is defined in Section 5.2. (e.g. ex-ante fee of entry in blockchain market) and cryptocurrency price therein, we are able to directly test the implication (18). Second, even if the transaction is not done by cryptocurrency, Proposition 5.2. tells us how we can interpret and predict the welfare-relevant performance of blockchain market. Because the application of the blockchain in state-contingent transactions is still in its initial stage, as of the time of the current study, we will try to empirically examine and evaluate these implications in the future projects.

7. Concluding Remarks

Blockchain and cryptocurrency have fundamental values. We develop a parsimonious model to propose the metric of the fundamental prices of them. In our model, all the fundamental values stem from asymmetric information and the ability of the blockchain to mitigate it. Since the trading through blockchain bears less risk of adverse selection, buyers are willing to use it and purchase the cryptocurrency. Specifically, by using the model of segmented markets with adverse selection, we analyze the coexistence and interactions of the

blockchain platform (*B*-market) and the traditional cash market (*C*-market) as two leading exchange venues operated in parallel.

The innovation in the security of blockchain platform makes itself an "exclusive exchange venue for highquality, yet expensive, assets": the price and quality of assets traded in blockchain platform become higher than that in the cash market. Due to these spreads in price and quality, buyers of assets have to tradeoff the price and quality. When the quality spread is small, or the underlying adverse selection is not severe, the cost of changing the trading platform from *B*-market to *C*-market is not significant. In this case, the increase in the price due to the higher security leads to a large migration and the decline in the trading demand in *B*-market. As a result of less active transactions in *B*-market, the demand and price of the cryptocurrency circulating on that blockchain decline. If the cost of migration from *B* to *C*-market is high due to the large quality difference, buyers accept the high price to avoid the cost of adverse selection, which pushes up the trading value in *B*market and the price of cryptocurrency. Therefore, the innovation in the blockchain has a non-linear effect on the price of cryptocurrency.

We also show that the welfare gain of buyers, who obtain access to the blockchain platform, is strictly positive. This implies that the blockchain managers can charge a positive fee for the access to the blockchain platform. We interpret the positive fee and welfare gain of buyers as the fundamental price of blockchain technology. This implies that, even if the blockchain is operated without cryptocurrency, the fundamental value of the technology is measurable. It is also shown that the price of the blockchain technology, welfare gain, and the price of cryptocurrency, if any, are perfectly correlated. If the innovation of the blockchain makes the transactions through *B*-market more active (in terms of trading value), then these fundamental values are increasing. However, the counterintuitive results show up when the quality spread is small or the adverse selection problem are not severe: as the higher security of the blockchain makes the price too expensive, it wipes out the demand in *B*-market. In this case, the innovation in blockchain reduces the welfare gain of buyers since it becomes exclusive too much, and it forces them to purchase the low-quality assets in *C*-market.

A couple of problems, such as the optimal level of the blockchain security and the empirical analyses cannot be investigated well without further data availability. Yet, this model provides the first theoretical framework to study the price of new digital asset: cryptocurrency and blockchain technology. In addition to the empirical challenges, one of the possible future projects is the extension of this framework into a dynamic setup. Specifically, this model can be modified to have a structure of overlapping generations and time-varying stochastic dividend of the assets, as already done by some of the finance literature on dynamic adverse selection (see literature review in the introduction).

Even though the cryptocurrency and blockchain technology are still in their nascent and pivot around speculations, given their growing influence and the future potential applications, we believe that the analyses of their fundamental value in theoretical models will have important implications and suggestions not only for financial markets but also for the entire economic activity.

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A Appendix: Generalized Model

This appendix provides the model with uninformed sellers: among the sellers, λ fraction of them are informed about the quality of their endowment, while the complement set of sellers are uninformed. The optimal behavior of informed sellers is same as the one provided in the subsection 3.2.

Optimal Behavior of Uninformed Sellers

Uninformed sellers cannot even distinguish the quality of their own assets. The behavior of them is determined by comparing the following returns:

$$W_0^U = (\pi + \phi(1 - \pi))\alpha,$$

$$W_C^U = P_C,$$

$$W_B^U = (\pi + (1 - \pi)(1 - \theta))P_B + (1 - \pi)\theta\phi\alpha.$$
(20)

The first one is the return from utilizing the asset for her own project, the second one is the return from selling the asset in *C*-market, and the last one is the return from selling it in *B*-market. In the last case, she obtains P_B if the transaction is completed, while she ends up with investing her asset into her project if the selling order is rejected. Each coefficient represents the probability of each case. Let

$$\tilde{\pi} = \pi + \phi(1 - \phi), \pi_0 = \pi + (1 - \pi)(1 - \theta)$$

and define a parameter

$$\xi \equiv \frac{\pi + (1 - \pi)(1 - \theta)}{\pi + \phi(1 - \pi)(1 - \theta)} \tilde{\pi}.$$

The behavior of uninformed sellers is analogous to that of informed sellers with low-quality assets since both of them fear the risk of detection. As we can see from (20), however, the return from selling in *B*-market, W_B^U , is lower than that of informed sellers, $W_B^{I,L}$, because the expected continuation value when the order rejection and the expected price return from non-rejection are discounted by the risk of lemons. On the other hand, the return from selling in *C*-market is not affected by the risk of lemons. Namely, with 100-percent probability, they can unload the asset of unknown quality. As a consequences, once again, it becomes a price-liquidity tradeoff given the expected continuation value of the asset, which makes relatively low(high)- α sellers throw assets into *C*-market (*B*-market).

Based on these arguments, if the price in *B*-market is sufficiently low, such that $\xi P_B \leq P_C$, trading in *B*-market is out of their options: they try to sell in *C*-market or stay inactive. There is a unique threshold,

$$\alpha^{U} = \frac{P_{c}}{\tilde{\pi}}$$

that separates traders into seller in C-market and inactive agents. In this case, the amount of sell orders from uninformed traders is

$$\begin{split} S^{U}_{B} &= 0, \\ S^{U}_{C} &= (1-\lambda) F\left(\frac{P_{C}}{\tilde{\pi}}\right), \end{split}$$

and it directly corresponds to the supply amount: $K_i^U = S_i^U$.

On the other hand, if the price in *B*-market is sufficiently high, $\xi P_B > P_C$, uninformed traders split order into two markets because the higher price in *B*-market strictly outweighs the risk of holding lemons for high- α sellers. That is, there are two thresholds,

$$\alpha_0^U = \frac{P_C - \pi_0 P_B}{\phi \theta (1 - \pi)}, \alpha_1^U = \frac{\pi_0}{\pi + \phi (1 - \pi)(1 - \theta)} P_B,$$

which separate uninformed traders into three groups. As in the case of informed sellers of low-quality assets, uninformed sellers (i) sell the asset in *C*-market if $\alpha \le \alpha_0^U$, (ii) sell it in *B*-market if $\alpha \in (\alpha_0^U, \alpha_1^U]$, and (iii) otherwise stay inactive. Hence, the amount of sell orders from uninformed traders is

$$\begin{split} S_B^U &= (1-\lambda)[F(\alpha_1^U) - F(\alpha_0^U)],\\ S_C^U &= (1-\lambda)F(\alpha_0^U), \end{split}$$

and the supply after the screening by blockchain is

$$\begin{split} K^{U}_{B} &= (1-\lambda)\pi_{0}[F(\alpha^{U}_{1}) - F(\alpha^{U}_{0})], \\ K^{U}_{C} &= (1-\lambda)F(\alpha^{U}_{0}). \end{split}$$

Aggregate Supply and Market Quality

The supply functions in the previous subsections determine the aggregate supply, K_B^S and K_C^S , as well as the market quality, π_B and π_C . Let χ be the indicator function for $\xi P_B > P_C$: $\chi = \mathbb{I}_{\{\xi P_B > P_C\}}$. The aggregate supply just sums up the supply from both type of sellers:

$$K_{\rm C}^{\rm S} = \lambda (1-\pi) F(\alpha_{\rm I}) + (1-\lambda) \left[\chi F(\alpha_0^{\rm U}) + (1-\chi) F\left(\frac{P_{\rm C}}{\tilde{\pi}}\right) \right]$$
(21)

$$K_B^S = \lambda \left\{ \pi F(P_B) + (1 - \pi)(1 - \theta) \left[F\left(\frac{P_B}{\phi}\right) - F\left(\alpha_I\right) \right] \right\}$$

$$+ (1 - \lambda) \pi_0 \chi [F(\alpha_1^U) - F(\alpha_0^U)].$$
(22)

By tracking the share of H-type assets in the supply, we can derive the market qualities in both markets.

$$\pi_{C} = \frac{(1-\lambda)\pi \left[\chi F(\alpha_{0}^{U}) + (1-\chi)F\left(\frac{P_{C}}{\bar{\pi}}\right)\right]}{K_{C}^{S}}$$
(23)

$$\pi_B = \frac{\lambda \pi F(P_B) + (1 - \lambda) \pi \chi [F(\alpha_1^U) - F(\alpha_0^U)]}{K_B^S}.$$
(24)

The determination of Q is the same as before.

A1. Numerical Examples for the General Model

The analyses in the main text focused on the blockchain market by setting $\pi_C = 0$, *i.e.*, there is no high-quality assets traded in the cash market. Given that the real economy still has most of the transactions going through the cash market, the behavior of π_C needs to be clearly stated.

A1.1. Effect of Security Improvement

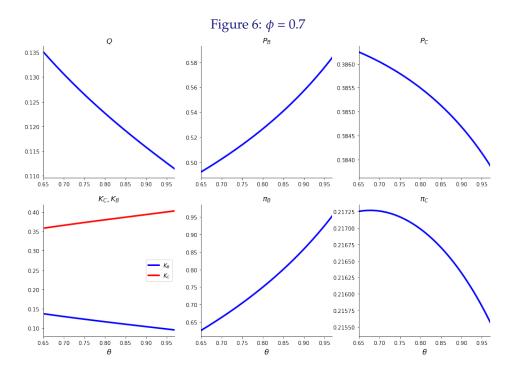
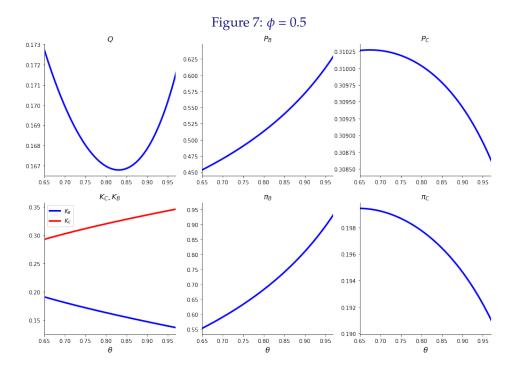


Figure 6 plots the effect of θ on the economic variables when the adverse selection is not severe ($\phi = 0.7$).³² As we have anticipated, the security improvement of blockchain technology brings about the higher price P_B and quality π_B in *B*-market. However, the direct rejection of θ fraction of low-quality assets, as well as the higher price, will have negative effects on the total trading volume in *B*-market. The negative effect of K_B dominates the positive effect of P_B because a high ϕ makes it easier for buyers to change their trading platform from *B*-market to *C*-market. As a consequence, the demand for cryptocurrency and its price *Q* become lower as θ increases.



³²Parameter values for the numerical examples are given by $\lambda = 1$ and $\pi = 0.3$.

As the adverse selection problem becomes more severe, it becomes more costly for buyers to migrate to *C*-market. In this case (we set $\phi = 0.5$), the improvement in the blockchain technology has the effects as in Figure 7. When θ is small, the difference between π_B and π_C is minimal. Thus, accepting a higher price in *B*-market is perceived as more costly than the improvement of the average quality. Therefore, a marginal increase in θ wipes out more traders than it attracts, leading to larger decline in the trading volume in *B*-market than the increase in P_B . The resulting *Q* is, therefore, downward sloping.

On the other hand, when θ is high, the difference of the average qualities between two markets is significant. In this situation, even if a higher θ induces a higher price P_B , this does not trigger a large migration since the buyers try to avoid a significantly higher uncertainty in *C*-market. In this case, the increment in the price dominates the decline in the transaction volume in *B*-market. As a result, the transaction value P_BK_B and the cryptocurrency price *Q* increase.

B Appendix : Proof

B1. Proof for Proposition 3.2. and 3.2.

The following argument proves the claim under the generalized model in Appendix A Making $\lambda = 1$ proves the proposition for the benchmark model.

Our arguments start from two conditions. In the buyers' problem, our guesses are

$$P_B \tilde{\pi}_C > P_C \tilde{\pi}_B \tag{25}$$

and

$$\pi_B > \pi_C. \tag{26}$$

Given these, the buyers' partial equilibrium implies that

$$\frac{P_B}{\tilde{\pi}_B} - \frac{P_C}{\tilde{\pi}_C} = (1 - K) + (\tilde{\pi}_B - \tilde{\pi}_C)K_C - (1 - K) > 0.$$

Therefore, we have shown that the inequality (25) holds in the equilibrium as long as the guess (26) is correct (note that (26) and $\tilde{\pi}_B > \tilde{\pi}_C$ are equivalent).

As the next step, we obtain (23) and (24) in the general equilibrium under the guess (26) (and (25)). By letting $\Delta \pi \equiv \pi_B - \pi_C$ and *F* be uniform, we have

$$\Delta \pi = \frac{\pi}{K_B K_C} \left[L - \lambda (1 - \lambda) (1 - \pi) (1 - \theta) \beta_0^U \frac{\Delta P}{\phi \theta} \right]$$
(27)

where $\Delta P = P_B - P_C$ and

$$\begin{split} L &= \lambda (1-\pi) \alpha_I (P_B + \beta_1^U) + (1-\lambda) \beta_0^U (\lambda (1-\pi) P_B + (1-\lambda) (1-\pi_0) \beta_1^U), \\ \beta_0^U &= \frac{P_C}{\tilde{\pi}} + \chi \left(\alpha_0^U - \frac{P_C}{\tilde{\pi}} \right), \beta_1^U = \chi (\alpha_1^U - \alpha_0^U). \end{split}$$

Since both of $\alpha_0^U - P_C / \tilde{\pi}$ and $\alpha_1^U - \alpha_0^U$ are (positively) proportional to $\xi P_B - P_C$, we have $\beta_0^U > 0$ and $\beta_1^U \ge 0$. Therefore, L > 0. Moreover, from (4) and (5), the difference of prices is

$$\Delta P = (\tilde{\pi}_B - \tilde{\pi}_C)(1 - K_B)$$

= $(1 - K_B)(1 - \phi)\Delta\pi$, (28)

where (22) obviously implies $K_B < 1$. By plugging this into (27), we obtain

$$\Delta \pi = \frac{\pi}{K_B K_C} \left[L - \lambda (1 - \lambda) (1 - \pi) (1 - \theta) \beta_0^U \frac{(1 - K_B) (1 - \phi)}{\phi \theta} \Delta \pi \right]$$

$$\therefore \Delta \pi = \frac{\frac{\pi}{K_B K_C} L}{1 + \frac{\pi}{K_B K_C} \lambda (1 - \lambda) (1 - \pi) (1 - \theta) \beta_0^U \frac{(1 - K_B)(1 - \phi)}{\phi \theta}} > 0.$$

Thus, the guess (26) holds in the general equilibrium, and (28) implies $P_B > P_C$.

B2. Proof for Proposition 4.1.

Suppose that we have $\alpha_I > 0$. Then the equilibrium solves

$$K_{C}^{S} = (1 - \pi) \frac{P_{C} - (1 - \theta)P_{B}}{\theta\phi}, K_{B}^{S} = \pi P_{B} + (1 - \pi)(1 - \theta) \left(\frac{P_{B} - P_{C}}{\phi\theta}\right),$$
(29)
$$K_{B}^{D} = 1 - \frac{P_{B} - P_{C}}{(1 - \phi)\pi_{B}}, K_{C}^{D} = \frac{P_{B} - P_{C}}{(1 - \phi)\pi_{B}} - \frac{P_{C}}{\phi},$$
$$\pi_{B} = \frac{\pi P_{B}}{K_{B}}.$$

Let $S = (P_B - P_C)/P_B$ be the normalized spread across markets. Then, rearranging the trading volumes gives

$$\begin{split} K^D_B &= 1 - \frac{S}{\pi(1-\phi)} K^S_B, \frac{K^S_B}{P_B} = \pi + (1-\pi)(1-\theta) \frac{S}{\phi\theta}, \\ K^S_C &= \frac{1-\pi}{\phi} P_B \left(1 - \frac{S}{\theta}\right), K^D_C = \frac{SK^S_B}{\pi(1-\phi)} + \frac{P_BS}{\phi} - \frac{P_B}{\phi} \end{split}$$

By equating $K_C^S = K_C^D$ and substituting K_B^i s, we get a quadratic equation for *S*. Namely, in the equilibrium, *S* solves

$$\frac{S}{1-\phi} + \frac{(1-\pi)(1-\theta)}{\phi\pi\theta(1-\phi)}S^2 + \frac{S-1}{\phi} - \frac{1-\pi}{\phi} + \frac{1-\pi}{\theta\phi}S = 0$$

Note that the LHS is monotonically increasing in $S(\ge 0)$, and the condition $\alpha_I > 0$ is identical to $S < \theta$ by definition (7). Thus, in the equilibrium, $\alpha_I > 0$ if and only if

$$\frac{\theta}{1-\phi} + \frac{(1-\pi)(1-\theta)}{\phi\pi\theta(1-\phi)}\theta^2 + \frac{\theta-1}{\phi} - \frac{1-\pi}{\phi} + \frac{1-\pi}{\theta\phi}\theta > 0,$$

which can be rewritten as

$$\theta^2(1-\pi) - \theta + \pi(1-\phi) < 0.$$

Note that if $\theta = 0$ then the LHS of this inequality is positive, while if $\theta = 1$ then it is negative. Thus, the smaller solution of the equation $\theta^2(1 - \pi) - \theta + \pi(1 - \phi) = 0$ is between 0 and 1. We set this solution as θ_0 . Thus, $\alpha_I > 0$ if and only if $\theta_0 < \theta \le 1$.

Next, suppose that $P_C - (1 - \theta)P_B \le 0$. This induces $\alpha_I = 0$ by definition (7), and the equilibrium solves

$$K_{C}^{S} = 0, K_{B}^{S} = \pi P_{B} + (1 - \pi)(1 - \theta)\frac{P_{B}}{\phi},$$

$$K_{B}^{D} = 1 - \frac{P_{B} - P_{C}}{\tilde{\pi}_{B} - \phi}, K_{C}^{D} = \frac{P_{B} - P_{C}}{\tilde{\pi}_{B} - \phi} - \frac{P_{C}}{\phi},$$

$$\pi_{B} = \frac{\pi P_{B}}{K_{B}}.$$
(30)

By using the market clearing in *C*-market and the definition of π_B , we obtain

$$K_B^D = 1 - \frac{mP_B - \phi}{(1 - \phi)\pi P_B} K_B^S, K_B^S = \left(\pi + \frac{(1 - \theta)(1 - \pi)}{\phi}\right) P_B,$$

with $m = 1 + \pi \phi + (1 - \pi)(1 - \theta)$. By clearing *B*-market, we have

$$P_B = \frac{\phi(\pi + (1 - \pi)(1 - \theta))}{(2 - \theta(1 - \pi))(\phi\pi + (1 - \pi)(1 - \theta))},$$
(31)

$$K_B = \frac{\pi + (1 - \pi)(1 - \theta)}{2 - \theta(1 - \pi)}.$$
(32)

Moreover, we can express the market clearing in *B*-market by using *S*:

$$K_B\left(1+\frac{S}{\pi(1-\phi)}\right) = 1$$

By plugging the explicit solution of K_B , we have

$$S = \frac{\pi(1-\phi)}{\pi + (1-\pi)(1-\theta)}$$

Since *S* is monotonically increasing in θ , the condition $P_C - (1 - \theta)P_B \le 0$ is identical to

 $\theta < S$,

that is

$$\theta^2(1-\pi) - \theta + \pi(1-\phi) \ge 0.$$

Therefore, the condition is $\theta \leq \theta_0$, and we have established that the equilibrium is continuous at $\theta = \theta_0$.

Corollary 3. When $\theta \leq \theta_0$, P_B , π_B , Q, and v_B are monotonically increasing in θ .

Proof. Results for P_B and π_B are obvious from (31) and (30) in Appendix B2.. See Appendix B3. for the results on Q and welfare.

B3. Proof for Corollary **B2**.

By using (31) and (32), we have

$$Q = \left(\frac{\pi + s}{1 + \pi + s}\right)^2 \frac{\phi}{\phi \pi + s}, \ s = (1 - \pi)(1 - \theta).$$

Then

$$\frac{dQ}{ds} \propto 2(\phi\pi + s) - (\pi + s)(1 + \pi + s) \equiv D_Q,$$

and

$$(1-\pi)D_Q = -\theta^2(1-\pi) + \theta - \frac{1+2\pi(1-\phi)}{1-\pi} < 0$$

where the last inequality comes from $\theta \leq \theta_0$. With the fact that $ds/d\theta < 0$, we have $dQ/d\theta > 0$.

B4. Proof for Proposition 4.1. and 4.2.

To see the uniqueness, we plot these K_B s against P_B (see Figure 5). Obviously, K_B^S is positive linear function in P_B . We can also check that K_B^D is concave, has only one inflection point in $P_B > 0$, and $\frac{dK_B^D}{dP_B} < 0$ for a sufficiently large P_B . Since $K_B^D = 1 > K_B^S$ at P_B such that $K_B^S = 0$, these two curves cross only once in $P_B > 0$.

Now, suppose that θ increases. This is represented by the red curves in Figure 5. We have

$$p^* = \frac{\phi}{2 - \pi(1 - \phi)} \tag{33}$$

such that $P_B \ge P_C \Leftrightarrow P_B \ge p^*$. Also, let

$$g \equiv \frac{1- heta}{ heta}, \ \eta \equiv 1 + \frac{\phi\pi}{2-\pi}.$$

In the equilibrium, we have $K_B^S = K_B^D \equiv K_B$, so that (14) and (13) are

$$K_{B} = P_{B} \left[\pi + \frac{(1-\pi)}{\phi} g \eta \right] - \frac{1-\pi}{2-\pi} g,$$

$$K_{B} = \frac{(1-\phi)\pi P_{B}}{((1-\phi)\pi + \eta)P_{B} - \frac{\phi}{2-\pi}}.$$
(34)

By equating these two equations and rearranging it in terms of $y \equiv P_B^{-1}$, we obtain

$$H(y,g) \equiv \left(\pi + \frac{1-\pi}{\phi}g\eta\right) - \frac{\pi(1-\phi)y}{((1-\phi)\pi+\eta) - \frac{\phi}{2-\pi}y} - \frac{1-\pi}{2-\pi}gy = 0.$$

For this function, we have

$$\frac{\partial H}{\partial g} = \frac{1-\pi}{\phi(2-\pi)} (2-\pi(1-\phi)-\phi y) > 0, \tag{35}$$

$$\frac{\partial H}{\partial y} = -\frac{\pi (1-\phi)((1-\phi)\pi+\eta)}{[((1-\phi)\pi+\eta)-\frac{\phi}{2-\pi}y]^2} - \frac{1-\pi}{2-\pi}g < 0.$$
(36)

Note that both inequality comes from $P_B > P_C$ (or equivalently $P_B > p^*$). These confirm, by the implicit function theorem, $dP_B/d\theta > 0$.

We rearrange the equation for π_B as

$$\pi_B = \frac{\pi}{\pi + \frac{1-\pi}{\phi}g(1 - \frac{P_C}{P_B})},$$

which implies

$$\operatorname{sgn}\left(\frac{d\pi_B}{d\theta}\right) = -\operatorname{sgn}\left(\frac{d\pi_B}{dg}\right) = \operatorname{sgn}\left(\frac{d}{dg}\left[g(1-\frac{P_C}{P_B})\right]\right)$$

By using (12), we can rewrite the inside of the last brackets:

$$1 - \frac{P_C}{P_B} = 1 - \frac{\frac{\phi}{2-\pi}(1-\pi P_B)}{P_B}$$
$$\propto \frac{2-\pi(1-\phi)-\phi y}{2-\pi}.$$

Hence, the last term can be calculated as follows.

$$\begin{split} \frac{d}{dg} \left[g \left(2 - \pi (1 - \phi) - \phi y \right) \right] &= 2 - \pi (1 - \phi) - \phi y - g \phi \frac{dy}{dg} \\ &= 2 - \pi (1 - \phi) - \phi y - g \phi \frac{\partial H / \partial g}{\partial H / \partial y} \\ &= \frac{2 - \pi (1 - \phi) - \phi y}{\partial H / \partial y} \left[\frac{\partial H}{\partial y} + g \frac{1 - \pi}{2 - \pi} \right] \\ &- \frac{2 - \pi (1 - \phi) - \phi y}{\partial H / \partial y} \frac{\pi (1 - \phi) ((1 - \phi)\pi + \eta)}{[((1 - \phi)\pi + \eta) - \frac{\phi}{2 - \pi} y]^2} \\ &> 0 \end{split}$$

where the second line comes from the implicit function theorem, from the third to last lines are due to (35), (36) and $P_B > p^*$. Thus, we established that $\frac{d\pi_B}{d\theta} > 0$.

As for the price Q, (34) yields

$$QB_S = P_B K_B = \frac{(1-\phi)\pi P_B^2}{((1-\phi)\pi+\eta)P_B - \frac{\phi}{2-\pi}}.$$

.

Since the right hand side does not contain θ , taking a derivative of the last term is

$$\frac{dQ}{d\theta} = \frac{dP_B}{d\theta} \frac{dQ}{dP_B} \propto (\eta + (1-\phi)\pi)P_B - \frac{2\phi}{2-\pi}.$$

Therefore, there is an inflection point

$$p^{**} = \frac{2\phi}{(\eta + (1 - \phi)\pi)(2 - \pi)},$$
$$\frac{dQ}{d\theta} \ge 0 \Leftrightarrow P_B \ge p^{**}.$$
(37)

which determines the sign of the effect:

Now, by using the implicit formula $H(P_B^{-1},g) = 0$ and the fact that $P_B H(P_B^{-1},g)$ is monotonically increasing in P_B , the condition (37) is identical to

$$A(\theta) \equiv g(1-\pi) (2\eta - h) + 2\pi [\phi - (1-\phi)(2-\pi)] \le 0.$$

Note that *A* is monotonically decreasing in θ (this can be confirmed by using $P_B > p^*$ again). By letting θ fluctuate from 0 to 1, we have the following result.

(i) If $\phi > (2 - \pi)/(3 - \pi)$, then $A(\theta) > 0$ for all $\theta \in [\theta_0, 1]$, which implies that $P_B > p^{**}$ always holds in the equilibrium, leading to a monotonically decreasing Q.

(ii) If $\phi \le (2 - \pi)/(3 - \pi)$, then A(1) < 0, so Q is decreasing in high- θ region. To understand more global behavior, we need to check if $A(\theta_0) \ge 0$. By seeing A as a function of g, we can define g^* that makes A(g) = 0 as

$$g^*(\phi) = \frac{2\pi(2 - \pi - \phi(3 - \pi))}{(1 - \pi)(1 - \pi(1 - \phi) + \frac{\phi\pi}{2 - \pi})}.$$

Since A(g) is increasing in ϕ , we have $dg^*/d\phi < 0$. Note that we are focusing on $\theta > \theta_0$, which means

$$g < g_0(\phi) \equiv rac{1- heta_0(\phi)}{ heta_0(\phi)}.$$

From the definition of θ_0 , we know θ_0 is decreasing and g_0 is increasing in ϕ . We also have $\lim_{\phi \to 0} g^*(\phi) > 0$ and $\lim_{\phi \to 0} g_0(\phi) = \mathbb{I}_{\{\pi < 1/2\}} \pi^{-1}$ because $\theta_0 \to \mathbb{I}_{\{\pi \ge 1/2\}} + \mathbb{I}_{\{\pi < 1/2\}} \frac{\pi}{1-\pi}$. Figure 8 shows the effect of a smaller ϕ on g^* and g_0 . We have following two possibilities.

(ii-a) Suppose that $\pi \ge 1/2$. Then there is ϕ_0 that solves

$$g^*(\phi) = g_0(\phi).$$
 (38)

 ϕ_0 is uniquely determined from the discussion above. In this case, if $\phi < \phi_0$, then A(g) < 0 for all $g < g_0$. That is Q is monotonically increasing in θ . If $\phi_0 < \phi < \phi_1$, then we have

$$A(g) \ge 0 \Leftrightarrow g \ge g^*.$$

Thus, we can define $\theta^* = 1/(1 + g^*) \in (\theta_0, 1]$, and *Q* is increasing when $\theta > \theta^*$ and decreasing when $\theta < \theta^*$.

(ii-b) Also, consider the case with $\pi < 1/2$. In this case, we have a unique $\pi^* \in (0, 1/2)$ that solves

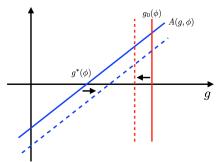
$$g^*(0) = \frac{2\pi(2-\pi)}{(1-\pi)^2} = \frac{1}{\pi} = g_0(0).$$

or equivalently

$$2\pi^3 - 3\pi^2 - 2\pi + 1 = 0.$$

If $\pi^* \leq \pi < 1/2$, then $g^*(0) > g_0(0)$. This implies that we always have θ^* defined by $\theta^* = 1/(1 + g^*) \in (\theta_0, 1]$, and and Q is increasing when $\theta > \theta^*$ and decreasing when $\theta < \theta^*$. On the other hand, if $0 \leq \pi \leq \pi^*$, then the arguments go back to the case **(ii-a)** and the same results hold.





C Appendix: Welfare Analyses for Buyers under $\lambda = 1$

The buyers' welfare in aggregate is

$$v_{B} = \int_{\alpha^{*}} (\Delta \tilde{\pi} \alpha - \Delta P) dF + \int_{P_{C}/\phi} (\phi \alpha - P_{C}) dF$$

= $\frac{\Delta \tilde{\pi}}{2} (1 - \alpha^{*})^{2} + \frac{\phi}{2} (1 - \frac{P_{C}}{\phi})^{2}$
= $\frac{1}{2} \left[\pi (1 - \phi) P_{B} K_{B} + \frac{\phi}{(2 - \pi)^{2}} (1 - \pi + \pi P_{B})^{2} \right],$ (39)

where the second term comes from $\alpha^* = \Delta P / \Delta \tilde{\pi}$, and the last term comes from (12), (10), $K_j^S = K_j^D$, and the definition of π_B :

$$\Delta \tilde{\pi} = (1 - \phi) \frac{\pi P_B}{K_B}.$$

The property of the first term is given by Proposition 4.2., while the second term is monotonically increasing in θ . Furthermore, by using (34),

$$2v_B = ((1-\phi)\pi)^2 \frac{P_B^2}{P_B[\eta + \pi(1-\phi)] - \frac{\phi}{2-\pi}} + \frac{\phi}{(2-\pi)^2}(1-\pi + \pi P_B)^2.$$

Note that θ does not directly affect v_B in this expression. By letting

$$h \equiv \eta + \pi (1 - \phi),$$

we have

$$\frac{d2v_B}{dP_B} \equiv D_B = ((1-\phi)\pi)^2 \frac{P_B(hP_B - 2\frac{\phi}{2-\pi})}{(hP_B - \frac{\phi}{2-\pi})^2} + \frac{2\phi\pi}{(2-\pi)^2}(1-\pi+\pi P_B).$$

The second order derivative yields

$$\begin{split} \frac{dD_B}{dP_B} &= \frac{2((1-\phi)\pi)^2}{(hP_B - \frac{\phi}{2-\pi})^3} \left[\left(hP_B - \frac{\phi}{2-\pi} \right)^2 - hP_B \left(hP_B - \frac{2\phi}{2-\pi} \right) \right] + \frac{2\phi\pi^2}{(2-\pi)^2} \\ &= \frac{2((1-\phi)\pi)^2}{(hP_B - \frac{\phi}{2-\pi})^3} \frac{\phi^2}{(2-\pi)^2} + \frac{2\phi\pi^2}{(2-\pi)^2} > 0. \end{split}$$

We also have $P_B(\theta = 1) \equiv \hat{p}_1 = \frac{1-\phi + \frac{\phi}{2-\pi}}{h}$ and can check $D_B(P_B = \hat{p}_1) > 0$. Thus, if $\lim_{\theta \to \theta_0} D_B < 0$, there is a unique θ^* such that $D_B \ge 0 \Leftrightarrow \theta \ge \theta^*$, while if $\lim_{\theta \to \theta_0} D_B > 0$, then $D_B > 0$ for all θ .

The following formulas at $\theta = \theta_0$ simplify the analyses. First, as $\theta \searrow \theta_0$, we have

$$P_{\rm C} = \frac{\phi}{2 - \pi} \left(1 - \pi P_{\rm B} \right) = (1 - \theta_0) P_{\rm B},\tag{40}$$

$$\therefore P_B = \tilde{p} \equiv \frac{\phi}{\pi \phi + (1 - \theta_0)(2 - \pi)}.$$
(41)

Moreover, at $\theta \rightarrow \theta_0$, we have $\alpha_I \rightarrow 0$ by definition. Since the markets have to clear, at the limit,

$$\lim_{\theta \searrow \theta_0} K_B^D = \lim_{\theta \searrow \theta_0} \left(1 - \frac{P_B - P_C}{\pi_B (1 - \phi)} \right)$$

$$= \lim_{\theta \searrow \theta_0} \left(1 - K_C^D - \frac{P_C}{\phi} \right)$$

$$= \lim_{\theta \searrow \theta_0} \left(1 - (1 - \pi)\alpha_I - \frac{P_C}{\phi} \right)$$

$$1 - \frac{\lim_{\theta \searrow \theta_0} P_C}{\phi}$$

$$= 1 - \frac{1 - \theta_0}{\phi} \tilde{p}$$
(42)
$$- \frac{1 - \pi + \pi \tilde{p}}{\phi}$$
(43)

$$=\frac{1}{2-\pi}.$$
(43)

The first line is the definition, the second line is from the definition of K_C^D , the third line is from the market clearing condition in *C*-market, and the fourth and fifth lines are from the definition of θ_0 that gives $\alpha_I = 0$ and (40). The last line is the other expression from (40). Also, from (34)

$$\lim_{\theta \searrow \theta_0} K_B = \frac{(1-\phi)\pi\tilde{p}}{((1-\phi)\pi+\eta)\tilde{p} - \frac{\phi}{2-\pi}}.$$
(44)

Since markets have to clear, all of these expressions (42, 43, 44) have to be identical. That is

$$\frac{(1-\phi)\pi\tilde{p}}{h\tilde{p}-\frac{\phi}{2-\pi}} = 1 - \frac{1-\theta_0}{\phi}\tilde{p} = \frac{1-\pi+\pi\tilde{p}}{2-\pi},$$
(45)

at (41).

Let $D_{B,0} \equiv \lim_{\theta \searrow \theta_0} D_B$. By using the equality of the first and last term in (45),

$$\begin{split} D_{B,0} &\propto (1-\phi)\pi \frac{h\tilde{p}-2\frac{\phi}{2-\pi}}{h\tilde{p}-\frac{\phi}{2-\pi}} + \frac{2\phi\pi}{2-\pi} \\ &= (1-\phi)\pi \left(1-\frac{\frac{\phi}{2-\pi}}{h\tilde{p}-\frac{\phi}{2-\pi}}\right) + \frac{2\phi\pi}{2-\pi} \end{split}$$

By using (45) once again,

$$h\tilde{p} - \frac{\phi}{2-\pi} = \frac{(1-\phi)\pi\tilde{p}}{1-\frac{1-\theta_0}{\phi}\tilde{p}}.$$

Thus,

$$\begin{split} D_{B,0} &\propto (1-\phi)\pi \left(1 - \frac{\phi}{2-\pi} \frac{1 - \frac{1-\theta_0}{\phi} \tilde{p}}{(1-\phi)\pi \tilde{p}} \right) + \frac{2\phi\pi}{2-\pi} \\ &= \frac{\tilde{p}[(1-\theta_0) + (2-\pi)(1-\phi)] - \phi}{(2-\pi)\tilde{p}} + \frac{2\phi\pi}{2-\pi} \\ &\propto [(1-\theta_0) + (2-\pi)(1-\phi)] + 2\pi\phi - \frac{\phi}{\tilde{p}} \\ &= [(1-\theta_0) + (2-\pi) - \phi] + 2\pi\phi - \pi\phi - (1-\theta_0)(2-\pi) \\ &= 1 + (1-\pi)(\theta_0 - 2\phi). \end{split}$$

Note that θ_0 is decreasing function of ϕ and $\lim_{\phi \to 1} \theta_0 = 0$. Then, $\min_{\phi} D_{B,0} = \lim_{\phi \to 1} D_{B,0} = 2\pi - 1$. Therefore, if $\pi < \frac{1}{2}$, we can define a unique $\phi = \phi_2$ that solves

$$1 + (1 - \pi)(\theta_0 - 2\phi) = 0.$$

If $\phi \leq \phi_2$ or $\pi > 1/2$, then $D_B > 0$ for all $\theta \in (\theta_0, 1]$, and v_B is monotonically increasing. On the other hand, if $\pi \leq 1/2$ and $\phi > \phi_2$, then there is a unique θ^{**} such that $D_B \geq 0 \Leftrightarrow \theta \geq \theta^{**}$.

Welfare of sellers with non-lemons is

$$v_{S,NL} = \int_{P_B} \alpha dF + \int^{P_B} P_B dF$$
$$= P_B + \frac{1}{2}(1 - P_B)^2.$$

That of sellers with lemons is

$$\begin{aligned} v_{S,L} &= \int^{\alpha^{I}} P_{C} dF + \int_{\alpha^{I}}^{\frac{P_{B}}{\phi}} \left((1-\theta) P_{B} + \theta \phi \alpha \right) dF + \int_{\frac{P_{B}}{\phi}} \phi \alpha dF \\ &= P_{C} + \frac{\phi}{2} \left[\theta (1-\alpha^{I})^{2} + (1-\theta) (1-\frac{P_{B}}{\phi})^{2} \right]. \end{aligned}$$