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A Model of Secular Migration from Centralized to Decentralized Trade*

Zhifeng Cai[†] Feng Dong[‡]

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Abstract

A large number of financial assets are traded in both exchanges and over-the-counter markets (i.e., centralized and decentralized markets, CM and DM hereafter, respectively). Moreover, as documented by Biais and Green (2019), the 20th century has witnessed a secular migration of asset trade from CM to DM. To this end, this paper develops a tractable model on strategic selection of venue trading to study the causes and consequences of the endogenous coexistence of CM and DM. In the model, traders' choice of venue is shaped by the trade-off between information frictions in the CM and matching frictions in the DM. Closed-form solutions are obtained and used to characterize the endogenous share of trade across the two venues. We then use the model to evaluate two potential explanations of the migration from CM to DM: improvements in matching technologies and increases in the number of institutional investors. Surprisingly, while both forces could lead to more trade in DM, there exist parameter regions where the increase in the number of institutional investors leads to less trade in DM. We also obtain empirically testable implications that differentiate the two explanations.

Keywords: Exchange vs Over-The-Counter (OTC) Market; Adverse Selection; Search Frictions; Institutional Investors; Fragmented Financial Markets.

JEL Codes: D61, D82, D83, L10.

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1 Introduction

In the United States and many other developed countries, a large number of financial assets, such as derivatives, futures, swaps, loan resales, corporate bonds and equity, are traded in both exchanges and over-the-counter markets (i.e., centralized and decentralized markets).¹ Moreover, Biais and Green (2019) document the secular migration of corporate bond trading from centralized to decentralized markets in the past century.² In a related vein, as shown by Harris (2003), equity trading has become less centralized as well. On the one hand, centralized markets (CM), for example, the New York Stock Exchange, have terms of trade publicly displayed and dispense with search frictions by nature. On the other hand, decentralized markets (DM), i.e., over-the-counter (OTC) markets, are mainly characterized by search and bilateral bargaining.³ Motivated by the coexistence of frictional markets with different structures, we naturally raise the following questions: (i) Since trading parties could enjoy a publicly displayed price without search frictions in CM, why do some agents bother to trade in DM? (ii) When could CM and DM coexist for asset trading? (iii) Does the migration of asset trade from CM to DM have something to do with the increasing matching efficiency in DM and the increasing concentration of the financial sector? (iv) Do the recent attempts to reduce opacity in markets that suffer from information asymmetry necessarily increase social welfare?

To this end, we propose a tractable model of strategic selection of venue trading to study the coexistence of CM and DM. We characterize CM as centralized exchange markets with an adverse selection problem because asset quality is unobservable to buyers and DM as decentralized markets with bilateral trading and search and matching frictions, but agents are allowed to acquire asset-specific information to alleviate the adverse selection problem. Due to the trade-off between information frictions in the CM and matching frictions in the DM, coexistence of CM and DM arises endogenously in our model. We show that in equilibrium as matching efficiency in DM increases and the information cost decreases, more trade migrates from CM with adverse selection to DM with search frictions. This result is consistent with the secular migration of asset trading from CM to DM documented by Biais and Green (2007).

¹Quantitatively, equities are largely traded on exchanges right now, while US Treasuries are mostly traded in over-the-counter markets. Additionally, see Hasbrouck (2007) and O'hara (1995) for a comprehensive survey of market structure and Harris (2003) for the details of the coexistence of exchange and OTC markets.

²The first version of the paper by Biais and Green is 2007, and the paper was published in the Review of Economic Dynamics this year. Therefore, we cited both Biais and Green (2007) and Biais and Green (2019).

³See Duffie, Garleanu and Pedersen (2005), Lagos and Rocheteau (2009), Hugonnier, Lester and Weill (2014), Atkeson, Eisfeldt and Weill (2015) and Zhang (2018), among others, for the analysis of OTC markets. See Duffie (2012) for a survey.

This paper adds value to the literature in the following ways. First, we illustrate a novel interaction of information frictions and search frictions and their roles in explaining endogenous market coexistence. Second, by characterizing determinants of the migration of asset trading, the model lends insight into the heterogeneous welfare effect of a government asset purchase program. Third, and perhaps most importantly, after incorporating the increasing concentration, i.e., the increase in the number of institutional investors, into the baseline model, we derive empirically testable implications that may differentiate different theories of the migration from CM to DM.

As emphasized by Levine (2005), liquid provision and resource reallocation in secondary markets are among the key functions of the financial industry. Asset owners could enjoy market liquidity by transferring claims if secondary market functions well. However, adverse selection may dampen potential trade. To address information frictions, we introduce both adverse selection and costly state verification into our model. That is, in addition to posting a pooling price in CM, buyers could also choose to acquire costly information on asset payoffs. Then, they can propose an optimal contract with bilateral trading in DM.

In the benchmark model with no information asymmetry on asset payoffs, CM is shown to always dominate DM for asset trading in equilibrium, as the DM is subject to search frictions. When asset payoffs and liquidity shocks are private information, we show that market coexistence can be supported.⁴ On the one hand, the seller's liquidity shock is always private information. On the other hand, buyers could always stay uninformed about asset payoffs. Then, buyers could post a publicly displayed price in CM, at which demand equals supply. Alternatively, buyers can acquire costly information to avoid adverse selection in CM. The informed buyers could then propose a trading menu different from the unique price posted by uninformed buyers in CM. When sellers with high-quality assets self-select into the contracts offered by informed buyers, search frictions may emerge due to coordination failure. That is, information investment and search frictions are two aspects in DM. The equilibrium market coexistence can be characterized in closed form. We utilize this closed-form solution to conduct comparative statics and find that increasing matching efficiency can indeed lead to more trade in DM.

Apart from fundamental reasons such as improving matching technology, there could be other causes of the migration from CM to DM. In particular, increasing concentration, a force

⁴In Section 2, we will fully characterize three alternative cases, in which either of them is private information and both of them are private information. Meanwhile, see Geromichalos and Herrenbrueck (2016), among others, for the microfoundation of the liquidity shock.

that can be equally or more important, is missing from the analysis in our baseline model. Increasing concentration in the financial sector can be a crucial factor for our questions.⁵ Biais and Green (2019) documented that liquidity migrated from the exchange to the OTC market exactly when institutional investors and dealers became more important relative to retail investors. To this end, we explore how the increase in the number of institutional investors affects the relative trading volume between CM and DM. Analyzing this question requires a model with heterogeneous traders. We thus extend our baseline model to include both institutional investors and retail investors. The institutional investors are different from retail investors in that they care about the price impact of their selling orders in a centralized limit-order exchange environment. This gives them relatively more incentive to trade in DM. The model is still quite tractable and admits closed-form solutions.

We then conduct comparative statics with respect to the share of institutional investors. Surprisingly, we find that the increase in the number of institutional investors does not necessarily lead to more trade in DM. This is due to a counteracting general-equilibrium force, whereby more institutional investors may crowd out existing investors in DM. The logic is as follows: More institutional investors imply that there are more sellers in DM. More sellers in the DM tend to reduce the probability of matching with a potential buyer and hence crowd out existing sellers. Normally, this crowding-out effect is not very strong, as having more sellers enhances the value of entry from the buyers' side, and with more potential buyers, existing sellers are not much discouraged from DM. This is not the case in our model with indivisible assets of heterogeneous qualities. In this environment, relatively high-quality assets are traded in the DM to avoid the adverse selection issue. Hence, the fact that institutional investors have higher incentive to trade in DM means that their assets are on average of lower quality compared to retail investors. Thus, increasing numbers of institutional investors imply lower average asset quality in DM, reducing buyers' incentive to enter. As the mass of potential buyers decreases with more institutional sellers in the market, existing DM sellers are further crowded out of the market. This general equilibrium effect through asset market tightness could be strong enough to lead to less trade in DM.

Even in the parameter space where increasing concentration does lead to more trade in DM, we are able to derive empirically testable implications that help to disentangle this theory from other potential explanations, such as improvement in matching technology. Specifically, improvements in matching technologies would deliver a different implication regarding the

⁵We thank a referee for this point.

intensive margin: within the investors' class, a larger share of (retail or institutional) investors is willing to trade in DM. Increases in the number of institutional investors, however, may imply the opposite due to the crowding-out effect. Thus, our paper provides empirically testable implications that can help disentangle different explanations of the increase in decentralized trading.

Finally, we use the model to address the heterogeneous effect of a government asset purchase program, for example, the Troubled Asset Relief Program (TARP). We are particularly interested in the following question. If government is assumed to have access to a lower information cost, or a more efficient matching technology, will all sellers be better off with government intervention? We show that when government steps in with a self-financing scheme, sellers with high-quality assets are better off while the others are worse off. Therefore, even though in our simple exchange model, which is free of the incentive effect in production, a self-financing government asset purchase program does not necessarily make everyone better off.

The rest of this paper proceeds as follows. Section 2 models and analytically characterizes a stylized framework, in which agents choose trading venues between CM and DM based on their trading motives. Section 3 extends the model by introducing institutional investors. Section 4 considers various extensions and robustness checks regarding the timing of information investment, distributions of liquidity shocks, government intervention and more discussion of related literature. Section 5 concludes. We put all the proofs in the Appendix.

2 Model

2.1 Environment

The economy is populated by two kinds of risk-neutral agents and lasts for two periods. First, there is a unit measure of asset sellers. Each of them is endowed with one unit of an indivisible Lucas tree at the beginning of $t = 1$. The seller's utility function is $U^S(x, \delta) = c_1 + \delta c_2$, where $c_1, c_2 \geq 0$ denotes consumption at $t = 1$ and $t = 2$, and x and δ are the idiosyncratic asset payoff and discount factor, respectively. Therefore, sellers are heterogeneous in both common value and private value. For notational ease, we label them as seller- (x, δ) . For simplicity, we assume these two distributions are independent of each other. On the one hand, asset payoff is drawn from a continuous distribution $F(x)$ with support $[x_L, x_H]$. For simplicity, we set $x_L = 0$ and $x_H = 1$. The discount factor, on the other hand, conforms to a distribution $G(\delta)$ with support $[0, 1]$. Trees only deliver consumption goods at $t = 2$. We assume sellers cannot

produce. Therefore, a maturity mismatch may emerge if some sellers want to sell their trees to consume in $t = 1$. This is particularly true for sellers with $\delta = 0$.

Second, we assume there is a continuum of asset buyers. For simplicity, we assume no occupational choice between buyers and sellers.⁶ Buyers have access to a linear production technology with labor input at $t = 1$. There is no aggregate shock to this economy. However, we assume it is not feasible for sellers to issue contingent claims. Moreover, no credit is assumed to be enforceable. Additionally, the limited commitment makes it impossible for sellers to signal in the secondary market. Consequently, assets serve as a medium of exchange, *i.e.*, sellers could transfer asset ownership to buyers for consumption at $t = 1$. In turn, buyers would have to produce consumption goods to purchase the trees at $t = 1$ and consume the fruits at $t = 2$. Therefore, when considering liquidity, we exclusively mean market liquidity rather than funding liquidity.⁷

In addition to staying uninformed, buyers can also acquire costly information. More specifically, buyers could pay information cost κ with their labor disutility. Then, they could perfectly detect the payoff of any asset. The action of information investment is publicly observed. Each information investment can only verify the quality of one-unit asset. We denote buyer's utility function as $U^B = -l_1^B - \kappa \cdot \mathbf{1}_{\{\text{Info-invest}\}} + \mathbb{E}(c_2^B)$, denote the disutility from producing l_1^B units of goods, and c_2^B denotes the consumption goods at $t = 2$ from the trees the buyer purchased at $t = 1$.⁸ The free entry of buyers implies that they would earn zero profit from asset trading in equilibrium.

To fully characterize the expected revenue $\mathbb{E}(c_2^B)$, we need to specify the details on how assets are traded between sellers and buyers. On the one hand, if a certain buyer does not incur information cost, she would have no idea on the exact quality of assets. Thus, she can only buy assets with a publicly displayed price p , for which demand equals supply in equilibrium. On the other hand, if a buyer acquires costly information, she could follow uninformed buyers to post a publicly displayed price p . Alternatively, she could propose a trading menu for sellers self-selecting into the contract. Notice that informed buyers could detect the asset payoff x , but they still cannot directly observe δ , the discount factor of asset sellers. Without loss of

⁶Bolton et al (2011b) discuss the endogenous choice between financial service and real business.

⁷See Brunnermeier and Pedersen (2009) for the details on market and funding liquidity.

⁸Some asset trading is dealer-intermediated in our real life, with corporate bonds just being a case. We assume away the intermediation in this paper. It contributes to great tractability for our focus on equilibrium choice. In contrast, an oversimplified interpretation is that we combine the roles of dealers and buyers and are exclusively engaged in the trading frictions due to private information on heterogeneity of the seller side. The price of assuming way dealers in DM is that there is no room to use our model to discuss the bid-ask spread and other important dealer-related financial phenomena.

generality, informed buyers use the direct mechanism $\{q(x, \delta), \tau(x, \delta)\}$. When sellers with asset payoff x report their type as δ , $q(x, \delta)$ is the probability that an asset is transferred to buyers while $\tau(x, \delta)$ is the consumption paid to sellers.

We proceed by clarifying our definition of centralized and decentralized markets (CM/DM). The former is a market where assets are traded at a publicly displayed price p . That is, sellers could always successfully sell their assets in CM at p without any search frictions. In contrast, as noted by Duffie (2012), DM are characterized by search and matching. That is, it takes time for sellers and buyers to find their trading partners. Since we assume each information investment can *only* verify the quality of one unit of asset, sellers and informed buyers will take bilateral trading. Therefore, DM emerges in the bilateral trading since sellers may fail to coordinate with each other about which buyers to resort to. We assume matching technology $m(b, s)$ in DM is exogenously given, increases with both arguments, is homogeneous of degree one, $m(b, 0) = m(0, s) = 0$, and $m(b, s) \leq \min(b, s)$, where b and s denote the measure of buyers and sellers in DM.

Buyers and sellers move simultaneously. Buyers make their choice on information investment or not. Sellers decide whether and where to trade. For sellers who choose to go to DM but are not successfully matched, we assume they can no longer try CM and instead go directly to the next period.⁹ In our benchmark, we follow Diamond and Dybvig (1983) to model liquidity shock as simple as possible; see Geromichalos and Herrenbrueck (2016), among others, for a microfoundation of the liquidity shock. We assume δ conforms to a binomial distribution with $\delta \in \{0, 1\}$, $\Pr\{\delta = 0\} = \pi \in [0, 1]$, and $\Pr\{\delta = 1\} = 1 - \pi$. Finally, we use Figure 1 to summarize the time line.

2.2 Seller's Problem

As suggested above, buyers can incur fixed evaluation cost κ and then choose to go to the DM for asset trading. Then, buyers would have no information disadvantage on x in DM. The terms of trade in DM for seller- $(x, \delta = 0)$ are then determined by Nash bargaining under complete information. By complete information, we mean both asset payoff x and liquidity shock δ are publicly observable without any cost. It is worth noting that the seller's outside

⁹We also consider an alternative scenario in which DM and CM are connected. That is, sellers have no commitment and are allowed to put their order in both markets. If sellers are not matched in DM, they still have the opportunity to liquidate their assets in CM if they want to. Most of the qualitative conclusions in the context still hold.

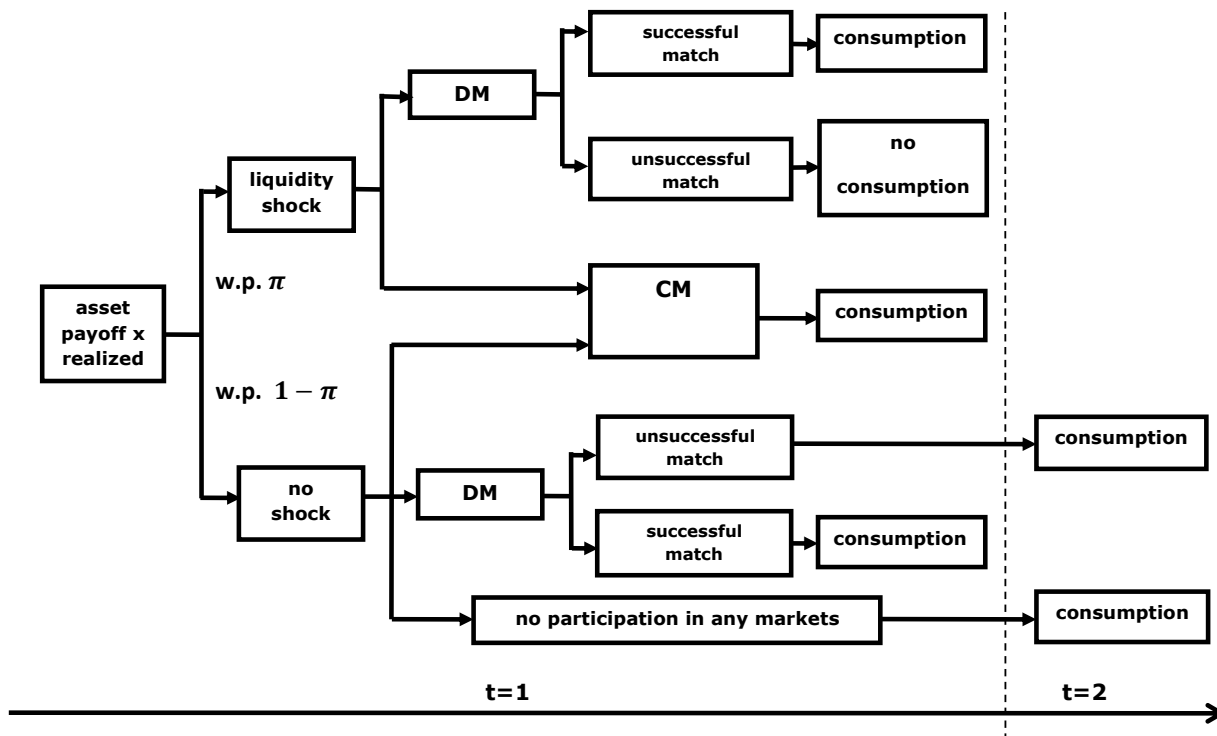


Figure 1: Time line

option crucially depends on δ . Since we assume sellers cannot trade in CM and DM at the same time, even though two markets coexist, the outside option of seller- (x, δ) going to DM is $x \cdot \mathbf{1}_{\{\delta=1\}}$.

For those with $\delta = 0$, the terms of trade are determined by $\max \{ \omega^\eta \cdot (x - \omega)^{1-\eta} \}$, which delivers $\omega(x) = \eta x$ for all x . When bargaining with buyers in DM, seller- $(x, \delta = 0)$ and seller- $(x, \delta = 1)$ have different outside options. The outside option is zero and x for the former and latter, respectively. Thus, strictly speaking, the bargaining setting $\max \{ \omega^\eta \cdot (x - \omega)^{1-\eta} \}$ is reasonable for the former but not for the latter group of asset sellers. Fortunately, this subtle observation does not overthrow our analysis to come. Even though the “bargaining power” of seller with $\delta = 1$ could be higher than that of seller with $\delta = 0$, they would never try DM. This claim is immediately obtained by the following argument. Buyers in DM would charge at least something from the trading surplus. As a result, the best possible terms of trade for seller- $(x, \delta = 1)$ would always be strictly lower than x . For those sellers, they could always gain x by waiting until $t = 2$. Thus, they would never try DM, even though the rule of splitting trading surplus for them is different from that for sellers with $\delta = 0$. Consequently, even though

liquidity shock is always unobservable, buyers can infer it from the seller's choice of trading venues.

For those with $\delta = 1$, there is no trading surplus in DM. As a result, although buyers cannot directly detect δ , they could infer that only sellers with $\delta = 0$ would show up in DM. Without loss of generality, we assume buyers always propose the contract as $\{q(x, \delta) = 1, \tau(x, \delta) = \eta x\}$ after paying information cost κ . Then, the objective function of seller- (x, δ) is formulated as below.

$$U^S(x, \delta) = \max_{\{\text{CM}, \text{DM}, \text{Delay}\}} \{c_1 + \delta c_2\},$$

where

$$\begin{aligned} a &= \begin{cases} 1, & \text{sell the assets at } t = 1 \\ 0, & \text{keep it until } t = 2 \end{cases}, \\ c_1 &= \max_{\{\text{DM}, \text{CM}\}} \left\{ \frac{m(b, s)}{s} \cdot \eta x, p(x) \right\} \cdot a, \\ c_2 &= a \cdot \mathbf{1}_{\left\{ \frac{m(b, s)}{s} \cdot \eta x > p(x) \right\}} \cdot \left[1 - \frac{m(b, s)}{s} \right] \cdot x + (1 - a) \cdot x, \end{aligned}$$

where b, s denote the measure of buyers and that of sellers in DM, respectively, and $p(x)$ the price of asset- x in CM. Notice that we employ random search in the benchmark.¹⁰ Thus, (b, s) does not differentiate the measure of trading parties in certain submarkets. For sellers- $(x, \delta = 0)$, they have to sell their asset at $t = 1$. Thus, their discrete choice is reduced to $\max_{\{\text{CM}, \text{DM}, \text{Delay}\}} \left\{ \frac{m(b, s)}{s} \eta x, p(x) \right\}$. For sellers- $(x, \delta = 1)$, in addition to participating in either DM or CM at $t = 1$, they could also exercise the option of waiting until the dividend is delivered at $t = 2$. Thus, their objective is formulated as $\max_{\{\text{CM}, \text{DM}, \text{Delay}\}} \left\{ \frac{m(b, s)}{s} \eta x + \left(1 - \frac{m(b, s)}{s} \right) x, p(x), x \right\}$.

2.3 Choice of Trading Venues

This part analyzes the choice of trading venues under both complete and incomplete information. For complete information, we mean both asset payoffs x and liquidity shock δ , *i.e.*, trading motives, are publicly observable.

Complete Information

Denote $p(x)$ as the price of asset- x in CM. Because of the free-entry condition on the buyer's side, the buyer's profit $x - p(x)$ from buying asset- x should be zero. As a result, $p(x) = x$ for

¹⁰We use random search to characterize frictions in DM throughout the paper. As shown in the Online Appendix, the main results are well preserved if we consider directed search.

all x with complete information. Then, we reach the following proposition.

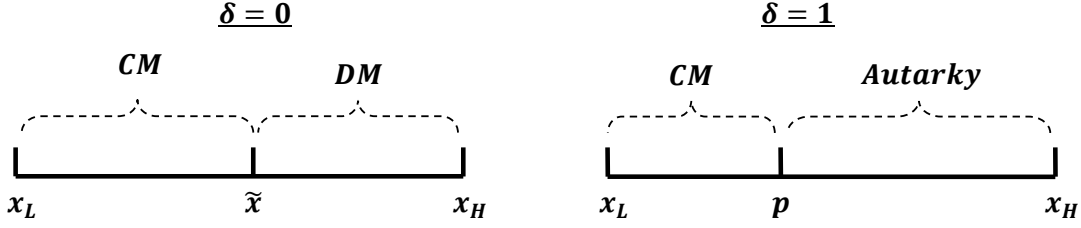


Figure 2: Choice of trading venues by seller- (x, δ)

Proposition 1 (Market Participation under Complete Information) *When there is no information asymmetry,*

1. Any seller- $(x, \delta = 0)$ would prefer CM to DM for asset trading at $t = 1$.
2. Any seller- $(x, \delta = 1)$ would never try DM. They are indifferent between trading in CM at $t = 1$ and waiting to consume at $t = 2$.
3. None of the buyers incur information investment. Instead, all of them concentrate in CM in $t = 1$.

The key message of this proposition is that when there is no information asymmetry on asset payoffs, CM are preferred to search frictions and bargaining in DM. We move on to the discussion with information asymmetry in the rest of this section.

Incomplete Information

When (x, δ) are private information of sellers, $p(x)$ is the same for sellers self-selecting to pool in CM at $t = 1$. Denote $p(x) = p$ in this case. Then, we have the following result on the choice of trading venues in partial equilibrium.

Proposition 2 (Market Participation under Two-dimensional Information Asymmetry) *When both asset payoff x and liquidity shock δ are the seller's private information, market participation is a choice function of seller- (x, δ) from $X \times \Delta = [0, 1] \times \{0, 1\}$ to $\{CM, DM, Autarky\}$ such that,*

1. For sellers with $\delta = 0$, there exists a cutoff point $\tilde{x} \in X$ such that if $x \geq \tilde{x}$, they would self-select into DM and enter CM otherwise at $t = 1$.

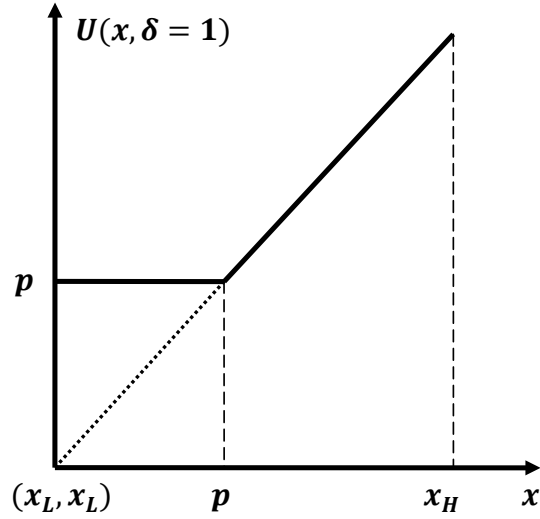


Figure 3: **Expected gain of seller-** (x, δ)

2. For sellers with $\delta = 1$, if $x < p$, they would choose CM, and if $x \geq p$, they would participate in neither DM nor CM at $t = 1$ but instead wait to consume at $t = 2$.
3. Given (\tilde{x}, p) , the utility function of seller- (x, δ) is refined as below.

$$U^s(x, \delta) = \max \left\{ \frac{x}{p + (\tilde{x} - p) \cdot \mathbf{1}_{\{\delta=0\}}}, 1 \right\} \cdot p. \quad (1)$$

The main message of this proposition is that when sellers are subject to a preference shock, those with high-quality assets tend to sell in DM while the others pool into CM. However, for those without a preference shock, since they have the outside option of waiting and consuming by themselves, they would never try DM with search and bargaining. Meanwhile, they would take advantage of CM if their asset's quality is low. For illustration purposes, we summarize the choice of trading venues by seller- (x, δ) and the associated gain $U^s(x, \delta)$ in Figures 2 and 3, respectively. Figures 2 and 3 jointly imply that the measure of sellers in DM is

$$s = \pi \cdot [1 - F(\tilde{x})], \quad (2)$$

Finally, based on Proposition 2, we show the results on market participation when either x or δ is private information.

Corollary 1 (Market participation with only one-dimensional information asymmetry) *When either asset payoff or liquidity shock is the seller's private information, market participation of sellers is as below.*

1. *(when only the trading motive is private information)* In this case, the result is the same as that with complete information on (x, δ) in Proposition 1. That is,

- (a) any seller- $(x, \delta = 0)$ would always prefer CM to DM for asset trading at $t = 1$;
- (b) any seller- $(x, \delta = 1)$ would never try DM. They are indifferent between trading in CM at $t = 1$ and waiting to consume at $t = 2$;
- (c) none of buyers incur information investment. Instead, all of them concentrate in CM at $t = 1$.

2. *(when only asset payoff is private information)* In this case, the result is very similar to the that of Proposition 2, but with $\pi = 1$.

- (a) For sellers with $\delta = 0$, there exists a cutoff point $\tilde{x}^* \in [0, 1]$ such that if $x \geq \tilde{x}^*$, they would self-select into DM and enter CM otherwise at $t = 1$.
- (b) For sellers with $\delta = 1$, if $x < p$, they would choose CM, and if $x \geq p$, they would participate in neither DM or CM at $t = 1$ but instead wait to consume at $t = 2$.
- (c) Buyers who are posting price p in CM would never accept sellers with $\delta = 1$. Thus, the equilibrium result would perform as if all sellers transferring their assets are $\delta = 0$, i.e., $\pi \equiv Pr(\delta = 0) = 1$.

That is, if only δ or x serves as private information, the seller's choice of trading venues is reduced to the case with complete information and that with two-dimensional informational asymmetry in Proposition 1 and 2, respectively. As a result, this corollary justifies why we stick to the general case with both x and δ as being the seller's private information when departing from the case with complete information. Moreover, we would rely on this corollary to simplify our arguments in Section 4.3 on welfare analysis by assuming only asset payoff is private information.

2.4 Asset Price in Centralized Market

There are two key variables in our partial equilibrium analysis. One variable is p , the price in CM, while the other is \tilde{x} , the cutoff point of choice between CM and DM. We use this

section and the next to reach two equations to determine (p, \tilde{x}) . Since buyers are assumed to be competitive in CM, none of them make positive profits in equilibrium. Thus, the price in CM is determined as below.

$$p = \frac{\pi F(\tilde{x})\mathbb{E}(x|x \leq \tilde{x}) + (1 - \pi)F(p)\mathbb{E}(x|x \leq p)}{\pi F(\tilde{x}) + (1 - \pi)F(p)}, \quad (3)$$

where the LHS of Eq. (3) is the buyer's cost for one unit of asset. The RHS is the average value of assets pooling in CM. Buyers are uninformed of the true value of each asset in CM. However, as implied in the above proposition, buyers have rational expectation of $F^{CM}(x)$, the true (truncated) distribution of asset payoffs in CM. One source is from those sellers with $(x \leq \tilde{x}, \delta = 0)$, while the other source is from those with $(x \leq p, \delta = 1)$. The numerator and the denominator of Eq. (3) are the total value and total measure of assets in CM, respectively.

Lemma 1 (Asset Price in CM) *Given any (\tilde{x}, π) , Eq. (3) has a unique solution as $p = P_{AS}(\tilde{x}, \pi)$.*

1. *For the general case, we have*

(a) $\partial P_{AS}/\partial \tilde{x} > 0$ and $\partial P_{AS}/\partial \pi > 0$.

(b) $x_L = P_{AS}(\tilde{x} = x_L, \pi) \leq p \leq P_{AS}(\tilde{x}, \pi = 1) = \mathbb{E}(x|x \leq \tilde{x}) \leq \min\{\tilde{x}, \mu\}$.

(c) $P_{AS}(\tilde{x}, \pi = 0) = x_L$. Thus, CM completely collapses when $\pi = 0$.

2. *When x is uniformly distributed: $x \stackrel{U}{\sim} X = [0, 1]$, we have an analytical solution such that*

$$p = \varphi(\pi) \cdot \tilde{x}, \quad (4)$$

where $\varphi(\pi) \equiv \frac{\sqrt{\pi}}{\sqrt{\pi+1}}$ and $Pr\{\delta = 0\} = \pi \in [0, 1]$.

Several comments are noted here. First, when $\pi = 1$, *i.e.*, all sellers would be hit by a liquidity shock at $t = 1$, then $p = P_{AS}(\tilde{x}, \pi = 1) = \mathbb{E}(x|x \leq \tilde{x})$, a classic problem on adverse selection. Second, when $\pi = 0$, *i.e.*, all sellers pooling in CM is simply due to selling lemons rather than liquidating for liquidity need; then, CM simply collapses because of severe adverse selection.

2.5 Free Entry of Information Investment

To make the analysis on market coexistence nontrivial, we have to assume the buyer's information investment κ is small relative to the average asset quality. Otherwise, buyers would have

no incentive to pay the cost and trade in the DM. In anticipating this scenario, both sellers and buyers would always concentrate in CM. The buyer's free entry condition in DM is then formulated as below.

$$\begin{aligned} \left[\frac{m(b, s)}{b} (1 - \eta) \mathbb{E}(x|x \geq \tilde{x}) - \kappa \right] \cdot b &= 0, \\ \frac{m(b, s)}{b} (1 - \eta) \mathbb{E}(x|x \geq \tilde{x}) - \kappa &\leq 0, \quad b \geq 0, \end{aligned}$$

We still need one more equation to pin down the relative share of buyers and sellers. This is done by the indifference condition of the marginal seller between CM and DM:

$$\frac{m(b, s)}{s} \eta \tilde{x} = p. \quad (5)$$

In what follows, we will assume that the matching function is Cobb-Douglas, i.e., $m(b, s) = \lambda b^m s^{1-m}$, to maintain tractability, where λ is the matching efficiency parameter and m is the relative share parameter. Then, we can link market tightness b/s to the endogenous equilibrium variables \tilde{x} and p using equation 5:

$$\begin{aligned} \lambda \left(\frac{b}{s} \right)^m \eta \tilde{x} &= p, \\ \frac{b}{s} &= \left(\frac{p}{\lambda \eta \tilde{x}} \right)^{\frac{1}{m}}. \end{aligned}$$

This expression can substitute for the market tightness in the buyer's free entry condition, and we have the next lemma that characterizes the buyer's free entry condition.

Lemma 2 (*Buyer's Free Entry Condition on Information Investment*) *Suppose that $m(b, s) = \lambda b^m s^{1-m}$; then, the buyer's free entry condition and marginal seller's indifference condition imply the following equilibrium relation between \tilde{x} and p :*

$$\begin{aligned} \left[\lambda \left(\frac{p}{\lambda \eta \tilde{x}} \right)^{\frac{m-1}{m}} (1 - \eta) \mathbb{E}(x|x \geq \tilde{x}) - \kappa \right] b &= 0, \\ \lambda \left(\frac{p}{\lambda \eta \tilde{x}} \right)^{\frac{m-1}{m}} (1 - \eta) \mathbb{E}(x|x \geq \tilde{x}) - \kappa &\leq 0, \quad b \geq 0. \end{aligned} \quad (6)$$

2.6 Characterization in General Equilibrium

In the remaining parts of this section, we move on to characterize the baseline model in general equilibrium. It turns out that we can obtain closed-form solutions for the endogenous coexistence of CM and DM.

Combining the *AS* condition (equation 3) and the *FE* condition (equation 6), we can solve for the general equilibrium (p, \tilde{x}) . It turns out that under the assumption of uniformly distributed x and the Cobb-Douglas form of the matching function, we can solve for the equilibrium in closed form. To see this, note that equation 4 implies that market price p can be written as an explicit function of \tilde{x} (under the assumption of uniform distribution). Substituting this expression into equation 6, we arrive at one equation and one unknown, which yields the following closed-form expression:

Proposition 3 (*Equilibrium Choice of Trading Venues*) Assume $x \stackrel{U}{\sim} X = [0, 1]$ and $m(b, s) = \lambda b^m s^{1-m}$. Then, the closed-form expression for \tilde{x} and p are given by

$$\begin{aligned} \tilde{x} &= \max \left\{ \min \left\{ \frac{\kappa}{\frac{1}{2}\lambda (\lambda\eta/\varphi(\pi))^{\frac{1-m}{m}} (1-\eta)} - 1, 1 \right\}, 0 \right\}, \\ p &= \varphi(\pi) \cdot \tilde{x}, \end{aligned}$$

where $\varphi(\pi) = \frac{\sqrt{\pi}}{1+\sqrt{\pi}}$.

We use Figure 4 to illustrate the above proposition. Intuitively, when κ is large enough, even though matching efficiency is high in DM and adverse selection is high in CM, only CM would survive for asset trading. When κ decreases, it is not only more likely that market coexistence could emerge but also that more trading would switch to DM given that coexistence can be sustained. As κ approaches zero, however, all trade would migrate to DM, and thus, $\tilde{x} = 0$.

Based on Figure 4, given any κ , we use the upper panel of Figure 5 to demonstrate the implication of the increase in matching efficiency in DM for choice of trading venues. It is clearly shown that by holding κ constant, both extensive margin and intensive margin changes with λ . The second panel suggests that \tilde{x} increases with π . The intuition is that when π decreases, the adverse selection tends to be more severe in CM; thus, DM appears more attractive for high-quality sellers, and thus, \tilde{x} decreases. The first three panels illustrate the monotone relationship between \tilde{x} and (κ, λ, π) , respectively. In contrast, the lower panel suggests the relationship between (η, \tilde{x}) is not monotone. When the seller's bargaining power η increases, which may be due to the increasing competition of buyers in DM, the direct effect is that \tilde{x} would decrease since the terms of trade in DM appear more attractive. Meanwhile, when η increases, the proportion of what buyers could acquire from trading in DM would decrease, and

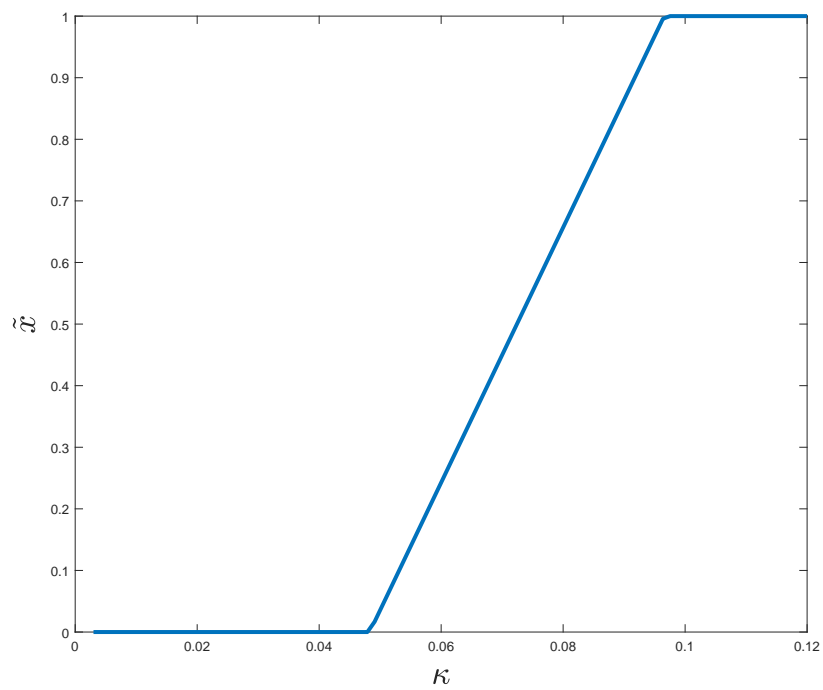


Figure 4: **Equilibrium choice of trading venues with different information cost κ**

thus, they have less incentive to enter. In turn, the seller's matched probability in DM would decrease, which would discourage sellers from choosing DM over CM. That is, \tilde{x} would increase in response to the second effect. The lower panel implies that the first effect is dominant when information cost κ is low enough, whereas it is just the opposite when κ is high.

2.7 Trading Share and Aggregation with Information Investment

After obtaining the equilibrium values on (p, \tilde{x}) , we obtain the determinants of trading share in both markets. According to Figure 5, the measure of sellers participating in either CM or DM at $t = 1$ is $\omega = \pi + (1 - \pi)F(p)$. As a result, *conditioning on* trade exercised at $t = 1$, the (truncated) trading share in CM is

$$\rho^{CM} = \frac{\pi F(\tilde{x}) + (1 - \pi)F(p)}{\pi + (1 - \pi)F(p)}, \quad (7)$$

Therefore, in the presence of market coexistence, we have the following comparative statics:

$$\frac{\partial \rho^{CM}}{\partial \lambda} < 0, \quad \frac{\partial \rho^{CM}}{\partial \pi} > 0, \quad \frac{\partial \rho^{CM}}{\partial \kappa} > 0, \quad \frac{\partial \rho^{CM}}{\partial \eta} \leq 0.$$

As implied in Eq. (7), the effect of λ , η , etc., on ρ^{CM} is through their impact on \tilde{x} , which in turn works on ρ^{CM} . First, when λ increases, say, due to IT improvement, the DM tends to be more attractive for sellers and thus the trading share in CM shrinks. The same logic applies to the argument on the effect of π on ρ^{CM} . Second, when π increases, the proportion of sellers with preference shock rather than selling lemons increases. The average quality of assets in CM increases, and thus, more sellers would trade in CM, which boosts ρ^{CM} . Finally and again, since the information cost κ has no role in neither \tilde{x} nor p due to the specification on matching function, it does not affect ρ^{CM} provided κ is low enough. In general, when κ decreases, due to financial deregulation or IT improvement, DM tends to absorb more sellers, *i.e.*, \tilde{x} would decrease with low ρ^{CM} . In sum, the exercise of comparative statics ρ^{CM} lends insight on the secular migration of bond trading in the past century, which is well documented by Biais and Green (2019). However, it is worth noting that the sign of $\partial \rho^{CM} / \partial \eta$ is ambiguous. The intuition is as follows. On the one hand, when η increases, the terms of trade in the intensive margin looks more attractive to sellers. On the other hand, the increase in η discourages buyers from making an information investment in the extensive margin. In turn, it would be less likely for sellers to be matched with buyers in DM. It is the trade-off between intensive and extensive margin by η that makes ρ^{CM} not monotone with η .

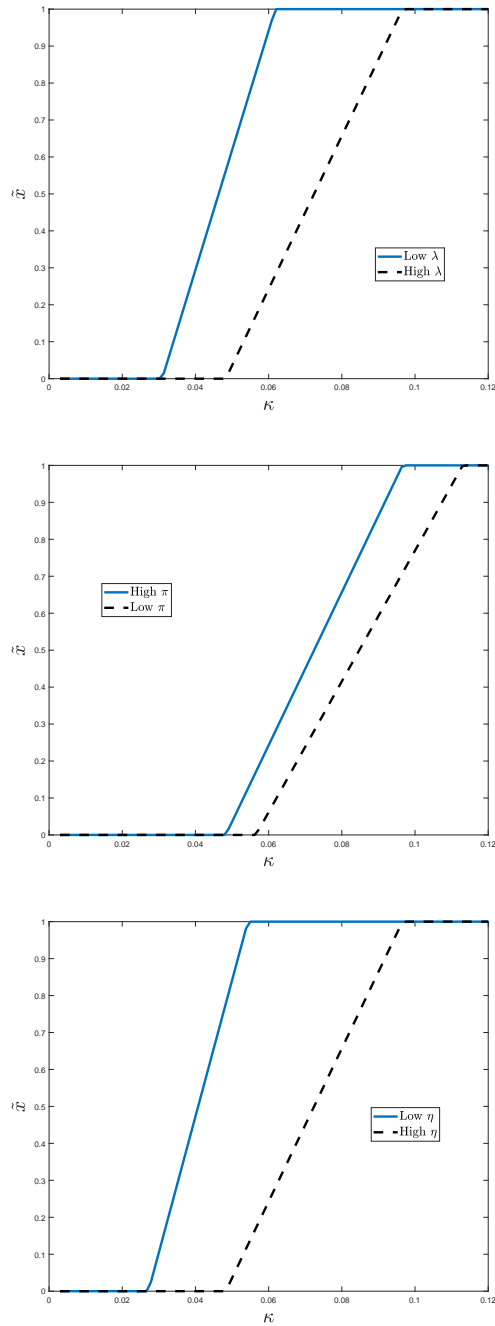


Figure 5: Comparative statics of the cutoff \tilde{x} with respect to information cost κ ; upper panel: matching efficiency λ ; middle panel: probability of liquidity π ; lower panel: buyer's bargaining power η in DM.

We close this section with a remark on information use. Since our model only considers an exchange economy, the aggregate asset payoffs are fixed. The aggregation with every seller having the same weight simply suggests that information investment by buyers is a waste of social resources. Following this line of argument, forbidding trade in DM is seemingly socially desirable. Moreover, we can rely on Proposition 3 to obtain the equilibrium values on p , the price in CM, as well as q , the weighted revenue. Then, we can verify that the emergence of DM with costly information acquisition dampens both the liquidity in CM and the average asset revenues.

However, since sellers are *ex ante* heterogeneous in asset payoffs and liquidity shock, the aforementioned simple weighted calculation is misleading to some extent. As shown in Proposition 3, market coexistence can be sustained under some conditions. In this scenario, sellers with high-quality assets prefer to bear search friction in DM rather than subsidize low-quality assets in CM. As a result, closing DM would make those sellers worse off. The discussion on the government asset purchase program equips us with a further illustration of this observation.

3 Institutional Investors

So far, we have illustrated the trade-off between CM and DM in the context of competitive markets and homogeneous sellers (traders). It is assumed that sellers in the CM are competitive in the sense that they take price as given; thus, they can be naturally interpreted as retail investors. However, increasing concentration, a force that can be equally or more important, is missing from the analysis in our baseline model. For instance, Biais and Green (2019) documented that liquidity migrated from the exchange to the OTC market exactly when institutional investors and dealers became more important relative to retail investors.

To this end, we use this section to extend our benchmark model to allow for the presence of institutional investors. The purposes of doing so are twofold. First, we can use the model to evaluate the wisdom that the increase in the number of institutional investors leads to more OTC trading (Biais and Green, 2019). Second, as argued in Biais and Green (2019), there are at least two potential explanations of the migration from CM to DM: (1) a reduction in search and match frictions and (2) an increase in the number of institutional investors. We thus derive different, empirically testable implications of the two theories, which may shed light on future empirical works to disentangle these two hypotheses.

The model is enriched in the following way. There are now two types of sellers: $1 - \alpha$ share

of them are retail sellers and are modeled exactly the same as in the previous section. The remaining α share of them are institutional investors. For simplicity we also assume that their types (x, δ) are uncorrelated regarding whether they are institutional or retail investors. We think of the key difference of institutional investors from their retail counterparts is that they care about the price impact of their sell orders and therefore have relatively lower incentive to trade in the CM. To maintain tractability, we assume that there is a wedge term τ imposed on the institutional investors: when they sell one unit of asset at market price p , the net revenue they obtain is $(1 - \tau)p$.¹¹ The wedge τ captures the negative price effect of trading in the CM by institutional investors. The advantage of introducing the wedge τ in this way is that it keeps our framework tractable, and equilibrium, as in the benchmark model, can still be solved in closed form. Other segments of the model are otherwise unchanged, and equilibrium is defined in the same way and hence is omitted here.

Next, we characterize the model. Given that there are two types of investors, the equilibrium now consists of the market price p , the cutoff of trading venue choice for retail investors \tilde{x} , and that for institutional investors \tilde{x}_I . The seller indifference conditions for the two types are given by:

$$\begin{aligned}\frac{m(b, s)}{s}\eta\tilde{x} &= p, \\ \frac{m(b, s)}{s}\eta\tilde{x}_I &= (1 - \tau)p.\end{aligned}$$

Thus, the ratio of two cutoffs is

$$\frac{\tilde{x}_I}{\tilde{x}} = 1 - \tau.$$

This implies that institutional investors' cutoff \tilde{x}_I is less than that of retail investors, and hence, they sell relatively low-quality assets in DM on average. This property of the model is natural given that they have higher incentives to trade in DM and given the cutoff property of the model. Moreover, we only need to keep track of one cutoff \tilde{x} and the equilibrium market price p . These two variables are pinned down by two equilibrium conditions, as summarized in the following proposition:

Proposition 4 *In the extended model with institutional investors, i.e., $\alpha, \tau > 0$, the equilibri-*

¹¹This pricing function can be micro-founded with monopoly selling assets facing a linear demand schedule. Our result extends to other formulations of the price impact cost, such as an isoelastic demand curve. We adopt this formulation because it yields a closed-form solution and hence analytical tractability.

um (\tilde{x}, p) is determined by the following two equations:

$$p = \mu \frac{\pi F(\tilde{x}) \mathbb{E}(x|x \leq \tilde{x}) + (1 - \pi) F(p) \mathbb{E}(x|x \leq p)}{\pi F(\tilde{x}) + (1 - \pi) F(p)},$$

$$\kappa = \frac{m(b, s)}{b} (1 - \eta) [\epsilon \mathbb{E}(x|x \geq \tilde{x}_I) + (1 - \epsilon) \mathbb{E}(x|x \geq \tilde{x})],$$

where

$$\mu = \frac{\mu_1}{\mu_2},$$

$$\mu_1 = (1 - \alpha) + \alpha (1 - \tau)^2,$$

$$\mu_2 = (1 - \alpha) + \alpha (1 - \tau),$$

$$\epsilon = \frac{(1 - \alpha) \pi (1 - F(\tilde{x}))}{\alpha \pi (1 - F(\tilde{x}_I)) + (1 - \alpha) \pi (1 - F(\tilde{x}))},$$

and the cutoff \tilde{x}_I is given by $\tilde{x}_I = (1 - \tau) \tilde{x}$.

The first equation is the competitive pricing equation where market price is equal to the expected asset quality traded in CM, whereas the second equation is the familiar buyer zero-profit condition. The two equations are both extended relative to their benchmark counterparts to account for the presence of the institutional investors. For equation 1, it is scaled by the factor μ . When there are no institutional investors ($\alpha = 0$) or when they exert no price impact ($\tau = 0$), then $\mu = 1$ and the equation collapses to the benchmark case. For the second equation, the average quality traded in DM is now a weighted average of the retail seller's quality and institutional seller's quality, with the weight given by ϵ .

The two equations can be simplified into a single equation characterizing the cutoff \tilde{x} .

Proposition 5 *The cutoff \tilde{x} is determined by the following nonlinear equation:*

$$\frac{1 - \mu_1 \tilde{x}^2}{1 - \mu_2 \tilde{x}} = \tilde{\kappa} \quad (8)$$

where μ_1 and μ_2 are given by the last proposition, and $\tilde{\kappa}$ is the transformed information cost and is given by

$$\tilde{\kappa} = \frac{\kappa}{\frac{1}{2} \lambda \left[\lambda \eta \left(\frac{\pi + \sqrt{\pi^2 - \mu \pi (1 - \pi) (\mu - 2)}}{\mu \pi} \right) \right]^{\frac{1-m}{m}} (1 - \eta)}.$$

One important aspect to note is that this equation is generically nonlinear due to the quadratic term. The nonlinearity is caused by the presence of two types of investors with different tendencies of trading in the two different markets. To see this, note that in the special

case where there are no institutional investors ($\alpha = 0$), $\mu_1 = \mu_2 = 1$ and the equation becomes linear:

$$\frac{1 - \mu_1 \tilde{x}^2}{1 - \mu_2 \tilde{x}} = 1 + \tilde{x}.$$

Interestingly, when there are only retail investors, the equation is also linear:

$$\frac{1 - (1 - \tau)^2 \tilde{x}^2}{1 - (1 - \tau) \tilde{x}} = 1 + (1 - \tau) \tilde{x}.$$

Thus, the nonlinearity only arises when both types of investors are present. Generally, this is a quadratic equation with two solutions, which implies equilibrium multiplicity.

Proposition 6 *Suppose $\alpha > 0$. Then, for sufficiently large τ and an appropriate level of κ , there exist multiple equilibria, i.e., multiple interior solutions to equation (8). The solutions for \tilde{x} are given by*

$$\tilde{x} = \max \left\{ \min \left\{ \frac{\tilde{\kappa} \mu_2 \pm \sqrt{(\tilde{\kappa} \mu_2)^2 - 4 \mu_1 (\tilde{\kappa} - 1)}}{2 \mu_1}, 1 \right\}, 0 \right\}.$$

The intuition for the nonlinearity proceeds as follows. In the case of just one type of investor, increasing the threshold \tilde{x} always raises the average asset quality in the DM pool. With two types of investors, this is not the case. Raising \tilde{x} has two opposing effects: first, it raises the average asset quality given investor type; second, it alters the relative shares of retail and institutional investors. The former force raises the overall average asset quality, whereas the latter could reduce the average asset quality if it reduces the proportion of retail investors, who have relatively high valuation. Depending on which force dominates, the slope for equation (8) can be either upward- or downward-sloping, leading to strong nonlinearity (see Figure 6).

The equilibrium multiplicity result naturally raises the issue of equilibrium selection. We select the low equilibrium, whenever there exists multiple equilibria because it corresponds to the unique equilibrium in the limit case where $\alpha = 0$ (no institutional investors) and $\alpha = 1$ (all institutional investors). Nevertheless, our results are robust to the selection of high equilibrium.¹²

With this equilibrium refinement, Figure 7 plots the key comparative statics results of the section. Panel A plots how \tilde{x} changes with α . As the share of institutional investors rises, \tilde{x} displays a nonlinear pattern: it first increases then decreases. This effect is associated with the nonlinear property that we have discussed before. Thus, the intensive-margin movement may

¹²The result regarding high equilibrium is available upon request.

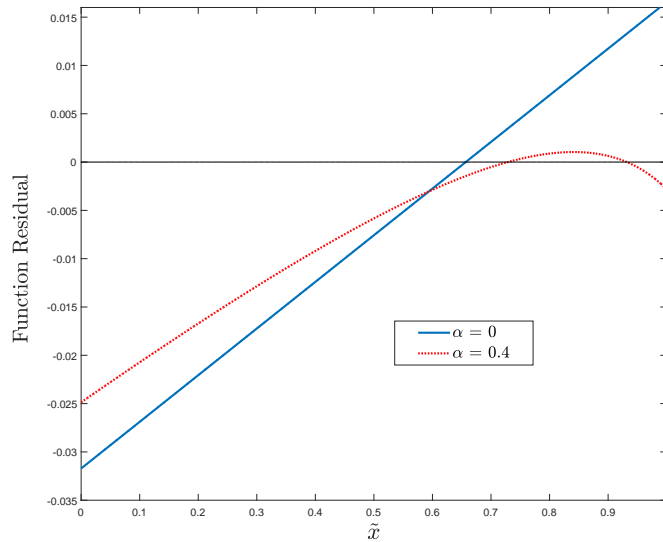


Figure 6: **Nonlinearity and multiplicity**

work against the increase in the number of institutional investors: more institutional investors implies that a smaller *fraction* of investors, both institutional and retail, are willing to trade in DM. This can be thought of as a crowding-out effect: if there are more entries of institutional investors who are akin to OTC trading, existing sellers are less likely to be matched and hence are more likely to switch to CM. This crowding-out effect is strong enough to overturn the conventional wisdom that increases in the number of institutional investors generate more OTC trading. As shown in panel C, for a wide range values of α (between 0 and 20%), it leads to less OTC trading. This observation is summarized in the following corollary.

Corollary 2 *Given a sufficiently large price impact cost τ and sufficiently small share of institutional investors α , an increase in the number of institutional investors leads to less equilibrium trading in the OTC market.*

How should we understand this corollary? Intuitively, it says that increases in α could lead to less equilibrium DM trading because by holding the investor type fixed, less investors are willing to trade in DM. This is shown in panel A of Figure 7, where the cutoff \tilde{x} increases with the share of institutional investors α . How does that happen? This arises through buyers' entry decision. Increases in the number of institutional sellers have two opposing effects on buyers' entry decision. First, with more sellers in the market, it is easier for the buyers to be matched

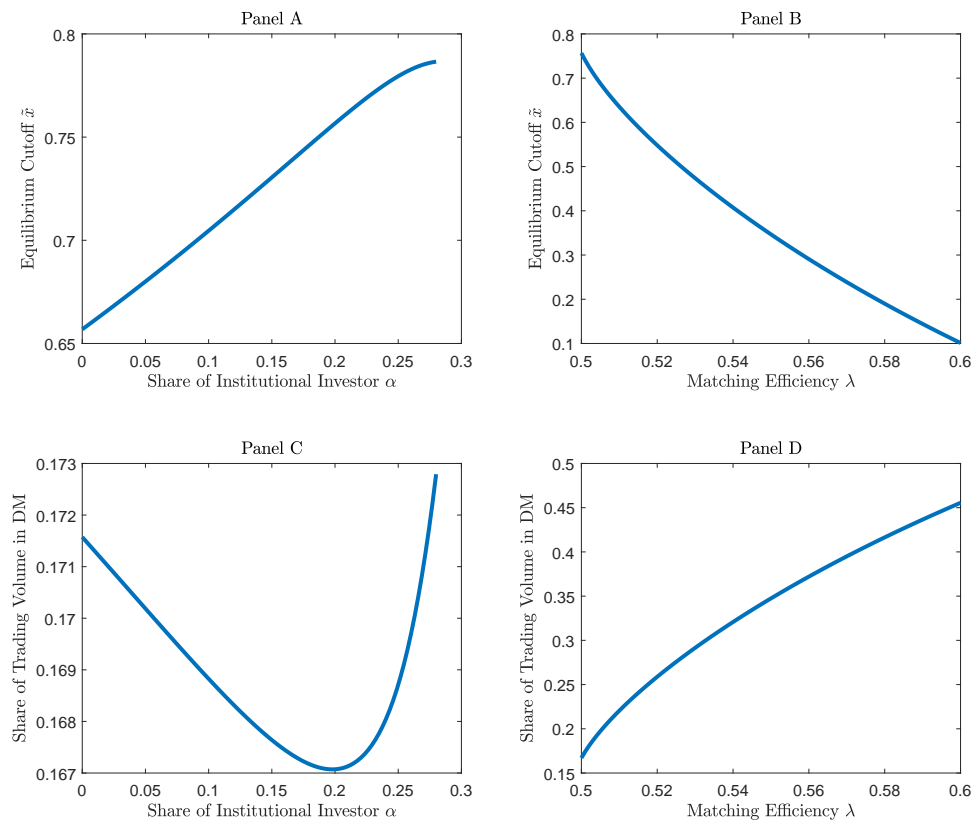


Figure 7: Comparative statics with respect to α and λ

and hence increases their incentive to enter. This effect occurs in any Walrasian market with search and matching frictions. However, there is a second, opposing, effect that occurs with markets in which assets are indivisible and of heterogeneous quality, as in this model. In the model, institutional investors on average sell relatively low-quality assets in DM, as their cutoff to enter DM is lower due to the price impact cost (equation 12). Thus, more institutional investors imply relatively lower average asset quality in DM, which reduces buyers' value to enter. When the second effect dominates, buyers choose to exit the market as a result of entry of institutional investors. This in turn results in a lower value of being a seller in DM, leading to a higher value of cutoff \tilde{x} , thus implying less trading volume in DM. This effect is more prominent when 1) the share of institutional investors is small so that percentage-wise, the second channel has a larger impact and 2) the price impact cost τ is higher so that institutional investors sell more, and even lower-quality, assets in DM.

Next we ask the following: Even in the parametric region where increases in institutional investors lead to more OTC trading, can we derive empirically testable predictions that disentangle this explanation from others, such as increases in matching efficiency? To do so, panel B and D plots the comparative statics of increasing matching efficiency. The two figures replicate the results from previous sections: an increase in matching efficiency leads to a lower threshold \tilde{x} and hence more OTC trading.

Thus, our model suggests that the intensive-margin statistics \tilde{x} could be a source of valuable information. If the increase in OTC trading were largely due to more institutional investors, then the movements at the intensive margin would not be substantial because of the counter-acting crowding-out effect. This is shown in panel A: when α increases from 0.2 to 0.3, the overall trade volume in DM is increasing but \tilde{x} is also largely increasing, implying that at the intensive margin, sellers are still dropping out. Whereas when the matching efficiency increases, the intensive margin \tilde{x} decreases, leading to higher percentages of investors in the DM. The theory thus suggests that tracking investor trading data, in particular, the time variation of the share of trade by either the institutional or retail investors in the OTC market, could possibly shed light on which theory is a more plausible candidate in explaining the increase in the OTC trading volume.

As a final remark, in the model we treat the price impact coefficient τ as exogenous. This simplifying assumption serves our purpose well. In particular, tractability is maintained and the closed-form solution enables us to answer the question of interest: Given institutional investors' concern about price impact, what would be the equilibrium outcome of increasing

concentration? Of course, the current framework could be extended in various ways to make it more realistic. For instance, the degree of price impact may be the outcome of strategic interactions across large institutional investors. Thus, the parameter τ may be endogenous and depend on the total mass of institutional investors. Exploring such possibilities is interesting, but note that, as long as institutional investors are more likely to trade in DM relative to retail investors, our main insight is unlikely to be altered. We view our paper as a first step toward understanding the impact of increasing concentration and leave various extensions, in particular endogenizing τ , to future research.

4 Extension and Discussion

In our baseline model in Section 2, we have assumed (1) buyers pay information cost before matched, (2) liquidity shock, δ , only adopts two mass points, zero and one, and therefore buyers could infer only sellers with $\delta = 0$ could show up in DM and (3) there exists no government intervention. For robustness concern, we consider the following extension in this section. To begin with, we consider the scenario in which buyers will not pay information cost if unmatched in DM. Secondly, we treat the general case on liquidity shock, in which δ is continuously distributed over an interval, just like the asset payoff x . Buyers in DM would offer an optimal contract to extract true value of δ for those sellers who self-select into DM. Thirdly, we revisit the government asset purchase program through the lens of our model. For illustration ease, all the extension is built off the baseline model in Section 2, i.e., we set $\alpha = 0$ so that there is no institutional investors. See the above Section 3 for the detailed characterization for the case with institutional investors. We conclude this section with more discussion of the related literature.

4.1 Alternative Timing

The first extension we consider is regarding the timing of information investment. In the benchmark model, we postulate that the decision of whether to make information investment is made before matching. In this section we explore the alternative timing where information investment decision is made after matching occurs.

We find that the result of the model would not be altered by this timing assumption. Intuitively, if information cost is only incurred after matching, then we can just re-scale it with the matching probability. And the resulting “expected” information cost would be equivalent

to the information cost in our benchmark model. Specifically, we start with our benchmark model with no institutional investors as in section 2. Recall that in this benchmark model, the buyer's first order condition, at any interior equilibrium, is given by:

$$\frac{m(b, s)}{b} (1 - \eta) \mathbb{E}(x|x \geq \tilde{x}) = \kappa,$$

where the left-hand-side is the expected pecuniary benefit of entering CM and the right-hand-side is the cost parameter κ . Note that the cost parameter κ is likely to reflect various costs associated with trading in DM, in addition to information investment. For instance, trading in DM may require higher entry costs compared to CM and there may be time cost of searching for counterparties. Thus, we will assume that the cost consists of two components: an entry cost κ_1 and an information cost κ_2 . In order to trade in DM, the buyers need to pay an upfront entry cost κ_1 . After successfully matched to counterparties, they then have an opportunity to make information investment regarding the asset of interest. Only if they decide to make information investment will the information cost κ_2 be incurred. Note that, this change in timing does not affect other segments of the model but the buyer's zero profit condition, which now becomes:

$$\frac{m(b, s)}{b} [(1 - \eta) \mathbb{E}(x|x \geq \tilde{x}) - \kappa_2] = \kappa_1,$$

or, equivalently,

$$\frac{m(b, s)}{b} (1 - \eta) \mathbb{E}(x|x \geq \tilde{x}) = \hat{\kappa},$$

where the normalized $\hat{\kappa}$ is a weighted average of entry cost κ_1 and information cost κ_2 such that¹³

$$\hat{\kappa} = \kappa_1 + \frac{\kappa_2}{\frac{m(b, s)}{b}}.$$

Given this observation, we obtain the following proposition:

Proposition 7 (Equilibrium Under Alternative Timing) Assume $x \stackrel{U}{\sim} X = [0, 1]$ and $m(b, s) = \lambda b^m s^{1-m}$. Then the closed-form expression for \tilde{x} and p are given by

$$\begin{aligned} \tilde{x} &= \max \left\{ \min \left\{ \frac{\hat{\kappa}}{\frac{1}{2} \lambda [\lambda \eta / \varphi(\pi)]^{\frac{1-m}{m}} (1 - \eta)} - 1, 1 \right\}, 0 \right\}, \\ p &= \varphi(\pi) \cdot \tilde{x}, \end{aligned}$$

where $\varphi(\pi) = \frac{\sqrt{\pi}}{1 + \sqrt{\pi}}$, and $\hat{\kappa} = \kappa_1 + \frac{\kappa_2}{\lambda [\lambda \eta / \varphi(\pi)]^{\frac{1-m}{m}}}$.

¹³We thank a referee for pointing this out.

Given this expression, comparative statics are very similar to our benchmark model and is hence omitted here.

As a final remark, note that we have only decoupled the timing decision in DM and we have implicitly assumed away the information acquisition choice in CM. This assumption can be micro-founded with free-riding behavior in a centralized exchange market. Given that a centralized exchange market is more transparent in terms of trading behavior, any private information will be transmitted quickly through market prices or order flows. This implies that a centralized market is particularly susceptible to free-riding behavior, as investors' trading decisions get unveiled quite fast. This, in turn, given investors less incentive to acquire information ex ante. Note that, this is perhaps less of a concern in a decentralized OTC market, where there is less regulation and little public information available. In light of these observations, we assume that there is information investment opportunities in DM but not in CM.

4.2 Liquidity Shock: from Discrete to Continuum Types

The second line of model extension focuses on switching from $\delta \in \{0, 1\}$ to $\delta \in [0, 1]$. In contrast to the baseline model with binomial distribution for δ , now it is worth noting that buyers can no longer infer the true value of δ . Furthermore, for tractability, we consider an optimal contract approach to characterizing the case with continuum types of δ by assigning all bargaining power to buyers in DM. Another technical assumption we make for the remaining part of the part is that, the matching technology in DM is Leontief, i.e., $m(b, s) = \lambda \cdot \min\{b, s\}$ with the matching efficiency $\lambda \in \{0, 1\}$.¹⁴ Then buyers can initiate optimal contract $\{q(x, \delta), \tau(x, \delta)\}$ after paying information cost κ in DM. Given any x , $q(x, \delta)$ and $\tau(x, \delta)$ denote the quantity of asset transferred to buyers and the consumption paid to sellers respectively if sellers report his type of private value as δ . Note that x is verifiable after buyers incurring information cost κ .

In the same spirit in the benchmark, there exists a cut-off value of κ , say $\bar{\kappa}'$, above which DM cannot not be supported whatever the contract buyers propose in DM. In contrast, the equilibrium with market coexistence is not only sustainable, but also stable if $\kappa < \bar{\kappa}^*$. Moreover, there exists another cut-off point $\underline{\kappa}^* < \bar{\kappa}^*$ such that $b < s$ in equilibrium if $\kappa < \underline{\kappa}^*$. Since the coexistence of CM and DM is the most intriguing part, we assume $\kappa < \bar{\kappa}^*$ holds. Moreover, to focus on the characterization of optimal contract by buyers in DM, we assume $\kappa < \underline{\kappa}^* < \bar{\kappa}^*$ throughout this subsection such that DM can not only be supported, but also there are more

¹⁴All the main results will be well preserved under Cobb-Douglas matching function, but the Leontief matching technology greatly simplifies the algebra in the case of continuum liquidity shocks.

buyers than sellers flowing into DM. We can prove that the qualitative results shown below are still held if $\kappa \in \underline{\kappa}^* < \bar{\kappa}^*$ (and $0 < b < s$ correspondingly).

Denote $U(x, \delta)$ as the gain of seller- (x, δ) by enrolling in the contract by buyers in DM. Now seller- (x, δ) makes her discrete choice among three alternatives.

$$\max \left\{ \underbrace{p}_{\text{CM}}, \underbrace{\frac{m(b, s)}{s} \cdot U(x, \delta) + [1 - \frac{m(b, s)}{s}] \cdot \delta x}_{\text{DM}}, \underbrace{\delta x}_{\text{Delay}} \right\}.$$

We focus on the most intriguing case in which CM and DM coexists. Thanks to the *Revelation Principle*, given any x , we could simply focus on buyer's direct mechanism in DM, which is formulated as below.

$$\Pi_B(x) \equiv \max_{\{q(x, \delta) \in [0, 1], \tau(x, \delta) \in [0, \infty)\}_{\mathbf{Z}_{DM}|x}} \left\{ \int_{\delta \in \mathbf{Z}_{DM}|x} [-\tau(x, \delta) + q(x, \delta) \cdot x] \right\},$$

subject to

$$\begin{aligned} U(x, \delta) &\equiv U_x(\delta; \delta) = \max_{\delta' \in \mathbf{Z}_{DM}|x} \{U_x(\delta; \delta')\}, \\ U_x(\delta; \delta') &\equiv [1 - q(x, \delta')] \cdot \delta x + \tau(x, \delta') \quad (IC), \\ \frac{m(b, s)}{s} \cdot U(x, \delta) + [1 - \frac{m(b, s)}{s}] \cdot \delta x &\geq \underline{U}(p, \delta x) \equiv \max\{p, \delta x\} \quad (IR). \end{aligned}$$

Similar to standard mechanism design, both Incentive Compatibility (*IC*) and Individual Rationality (*IR*) should be satisfied. What makes our setup challenging is that, buyer's mechanism design would affect Z_{DM} , the content of seller- (x, δ) self-selecting into the contracts in DM. Moreover, it is worth noting the outside option is type-dependent and thus may involve in the so-called countervailing incentive *a la* Lewis and Sappington (1989), Maggi and Rodriguez-Clare (1995) and Jullien (2000).

The following lemma on seller's choice of trading venues generalizes the results of Proposition 2.

Lemma 3 (*Seller's Choice of Trading Venues*) *For any seller- (x, δ) , given p in CM and contract $\{q(x, \delta), \tau(x, \delta)\}$ in DM, there exists cut-off values $\underline{\delta}(x)$ and $\bar{\delta}(x)$ such that,*

1. if $\delta \in [0, \underline{\delta}(x)]$, she sells her asset at CM;
2. if $\delta \in (\underline{\delta}(x), \bar{\delta}(x)]$, she sells her asset at DM;
3. if $\delta \in (\bar{\delta}(x), 1]$, she chooses not to trade.

We rewrite the *IR* condition of this mechanism design as below.

$$U(x, \delta) \geq V(x, \delta, p) \equiv \delta x + \frac{1}{\lambda} \max \{p - \delta x, 0\},$$

where $\widehat{\lambda} \equiv \frac{m(b,s)}{s}$ and thus $V(x, \delta, p)$ decreases with δ when $\delta x < p$ while increases when $\delta x > p$. The non-monotone property of V stems from the fact that, relative to DM, seller- (δ, x) have two outside options. One is sell at CM at price p while the other one is pure autarky, *i.e.*, participating in neither CM nor DM. When δx is low, the outside option with CM is larger than that in with autarky. It is just opposite when δx is high enough.

Secondly, given any x , Envelope Theorem suggests that

$$\frac{\partial U(x, \delta)}{\partial \delta} = [1 - q(x, \delta)]x \geq 0.$$

Combining these two observations yields the results in the lemma with

$$\begin{aligned} \underline{\delta}(x) &= \max \left\{ 0, \frac{p - \widehat{\lambda} \cdot U(x, \delta)}{(1 - \widehat{\lambda}) \cdot x} \right\}. \\ \bar{\delta}(x) &= \min \left\{ 1, \frac{U(x, \delta)}{x} \right\}. \end{aligned}$$

Based on the above lemma, we reach the optimal contract in DM and in turn obtain the explicit solution on $(\underline{\delta}(x), \bar{\delta}(x))$.

Proposition 8 (*Optimal Contract Offered in DM*) When $\delta \stackrel{U}{\sim} \Delta = [0, 1]$ and $m(b, s) = \lambda \cdot \min\{b, s\}$ and κ is small enough, given any x in DM, buyer's optimal contract is in the form as take-it-or-leave-it in the following form.

$$\{q^*(x, \delta) = 1, \tau^*(x, \delta) = \tau(x)\},$$

where

$$\tau(x) = \begin{cases} \frac{p+x}{2} & \text{if } x \in [p, \frac{2-\lambda}{\lambda} \cdot p] \\ \frac{p}{\lambda} & \text{if } x \in (\frac{2-\lambda}{\lambda} \cdot p, \frac{2}{\lambda} p] \\ \frac{x}{2} & \text{if } x \in (\frac{2}{\lambda} \cdot p, x_H] \end{cases}$$

In turn, we have

$$\underline{\delta}(x) = \max\left\{0, \frac{p - \lambda \cdot \tau(x)}{(1 - \lambda) \cdot x}\right\} = \begin{cases} 1 & \text{if } x \in [x_L, p] \\ \frac{(1 - \frac{\lambda}{2})p - \frac{\lambda}{2}x}{(1 - \lambda)x} & \text{if } x \in (p, \frac{2 - \lambda}{\lambda} \cdot p] \\ 0 & \text{if } x \in (\frac{2 - \lambda}{\lambda} \cdot p, \frac{2}{\lambda} \cdot p] \\ 0 & \text{if } x \in (\frac{2}{\lambda} \cdot p, x_H] \end{cases}$$

$$\bar{\delta}(x) = \min\left\{1, \frac{\tau(x)}{x}\right\} = \begin{cases} 1 & \text{if } x \in [x_L, p] \\ \frac{p + x}{2x} & \text{if } x \in (p, \frac{2 - \lambda}{\lambda} \cdot p] \\ \frac{p}{\lambda x} & \text{if } x \in (\frac{2 - \lambda}{\lambda} \cdot p, \frac{2}{\lambda} \cdot p] \\ \frac{1}{2} & \text{if } x \in (\frac{2}{\lambda} \cdot p, x_H] \end{cases}$$

We illustrate Proposition 5 in Figure 8 and 9 respectively the terms of trade by buyers and choice of trading venues by sellers.

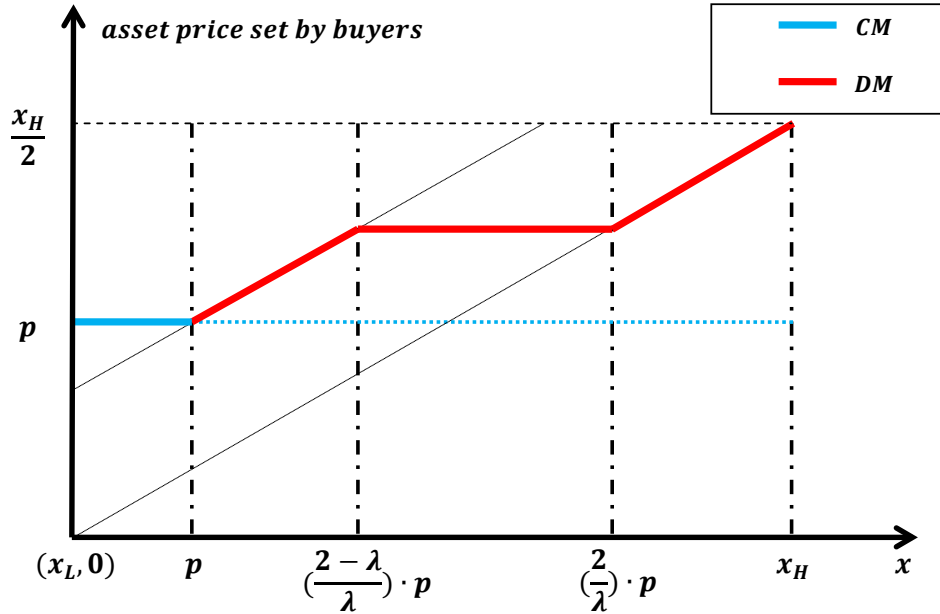


Figure 8: $(p, \tau(x))$: Assets Prices in CM and DM

Several remarks are made here. First of all, the optimal contract by buyers in DM only focus on sellers with $x > p$. On one hand, p is always an outside option of any seller- (x, δ) and thus buyers in DM would attract no sellers if $\tau(x, \delta) < p$. On the other hand, buyer's profit is $x - \tau(x, \delta)$. To make the profit non-negative, it must that they would trade with $x > p$ and

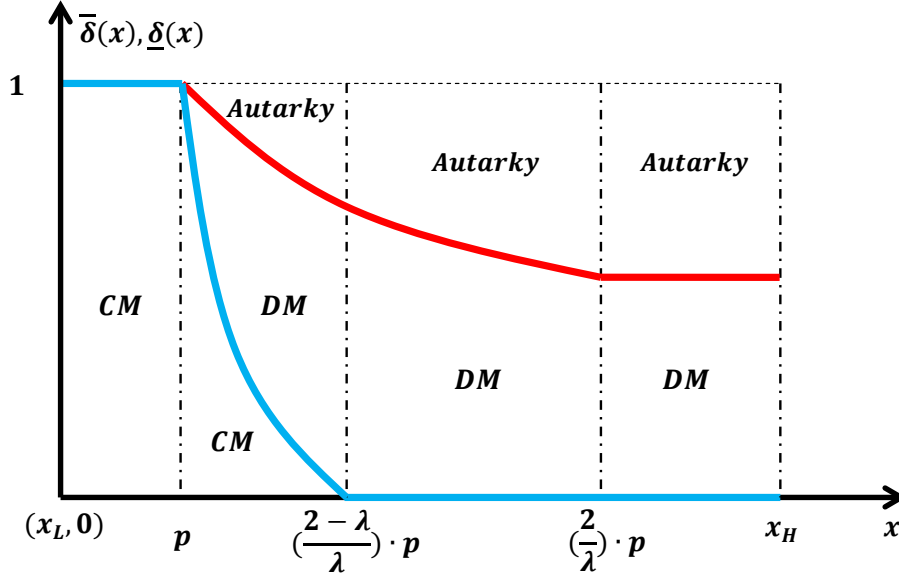


Figure 9: Seller's choice of trading venues

x can always be verifiable. Secondly, given price in CM p , seller's choice over CM, DM and autarky not depends on common value x , but also on private value δ . Thirdly, we are still in the position of partial equilibrium since price in CM is taken as given. Based on Proposition 8, p is solved in equilibrium as below.

$$p = \frac{\int_{x_L}^p x dF(x) + \int_p^{\min\{\frac{2-\lambda}{\lambda} \cdot p, x_H\}} x G\left(\frac{(1-\frac{\lambda}{2})p - \frac{\lambda}{2}x}{(1-\lambda)x}\right) dF(x)}{F(p) + \int_p^{\min\{\frac{2-\lambda}{\lambda} \cdot p, x_H\}} G\left(\frac{(1-\frac{\lambda}{2})p - \frac{\lambda}{2}x}{(1-\lambda)x}\right) dF(x)}, \quad (9)$$

where F and G denotes the CDF of x and δ respectively. Moreover, we have implicitly assumed $G(\delta)$ is a uniform distribution. However, even though $F(x)$ is a uniform distribution, the above equation has no analytical solution on p .

4.3 Government Purchase Program (TARP)

Information investment serves as buyer's natural response to alleviate adverse selection. However, if we aggregate the revenues by all sellers, then immediately we know that information acquisition is purely a resource waste in our exchange economy.¹⁵ In addition to information investment, the unmatched trading in DM also contributes to the deadweight loss. However,

¹⁵Buyers are assumed to be fully competitive and thus their gain is irrelevant for calculating the social welfare.

since sellers are heterogeneous in their asset payoff and trading motives, closing DM is not Pareto improvement. To this end, we address the heterogeneous effect of a government asset purchase program, for example Troubled Asset Relief Program (TARP).

Prior to the financial recession, mortgage-back securities (MBS) were considered to be information insensitive assets and thus there did not appear to exist an information asymmetry. However, the outbreak of the financial crisis reminded the market of the potential information asymmetry within the MBS market. Consequently, financial markets tended to be illiquid and some markets, such as the federal funds market, were also frozen. See Heider, Hoerova and Holthausen (2015) and Gale and Yorulmazer (2013) among others for the background description and theoretical explanation.

The US government launched the Troubled Asset Relief Program (TARP) to curb the recent financial crisis. More specifically, the US Treasury implemented the TARP by purchasing MBS from the financial institutions.¹⁶ In this section, we use the baseline model to address the implication of government intervention for the seller's welfare. We focus on the seller's welfare since buyers are assumed to be fully competitive and thus they would make zero profit in equilibrium. In particular, we raise the following question. Does a self-financing government intervention make all sellers better off? If not, how would the heterogeneous treatment effect be related to the seller's asset quality?

Thanks to Corollary 1, we can concentrate on the simplified case with $\pi = 1$, *i.e.*, all sellers are hit by liquidity mismatch and thus have to sell their assets to buyers before the asset payoffs are realized. Then we can index each seller as seller- x rather than seller- (x, δ) in the baseline. The assumption that $\pi = 1$ is made without loss of generality. An alternative assumption would be that while π is less than 1, the government has the power to force all traders to sell. This would be equivalent to our current formulation. Due to the free entry condition of information investment and trading in the decentralized market (DM), if the government has to incur a higher information cost than do the normal buyers in the baseline, or if its matching efficiency in the DM is lower, then the government would make a loss from its intervention. To make the analysis non-trivial, we assume the asset purchase program is self-financing. In turn we make the following assumption.¹⁷

Assumption 1 *The government enjoys a lower information cost than private buyers.*

¹⁶See the following link for more details of this program: <http://www.federalreserve.gov/bankinfo/tarpinfo.htm>.

¹⁷Alternatively, we could assume $\lambda_g > \lambda_b$, *i.e.*, the government would enjoy a higher matching efficiency in DM after paying the same information cost. Moreover, we can easily relax the assumption that $\kappa_b < \bar{\kappa}$.

How do we understand the assumption that the government is more efficient in acquiring information compared to private buyers? Our preferred interpretation is that the government could have better access to information about the macroeconomic conditions and hence the *aggregate* component of asset payoffs. For instance, the Federal Reserve might have access to confidential data at national level that facilitates it to make forecasts that otherwise cannot be made by private agents without access to these data. Alternatively, it may also have private information about, say, future paths of interest rates that is not known to private agents, and is crucial for asset price fluctuations. On the other hand, we do acknowledge that private agents may have superior information regarding the *idiosyncratic* components of asset payoffs. In that case, we could instead assume that the government enjoys higher matching efficiency. Both lower information cost and higher matching efficiency would give rise to very similar results regarding government intervention, because in the end what matters for asset market equilibrium is the “re-scaled” information cost, that is, κ weighted by matching probability.

To implement the program, the government issues perfectly enforceable debts to buyers at the beginning of $t = 1$. Thus the government receives consumption goods produced by buyers. When government steps into asset markets, it does not necessarily have an information advantage over the uninformed buyers in the baseline on asset payoffs. We adopt a more reasonable assumption by treating the government in a similar position as uninformed buyers. That is, the government could always set up a pooling price in the CM. Alternatively, the government can make an information investment and kick off bilateral trade with sellers in the DM. They can also launch the trade in both markets in the same time.

In sum, with these consumption goods at hand, the government buys seller’s assets in the CM, and decides whether or not to pay the information cost and buy assets from DM. At $t = 2$, the government receives consumption goods from the pooling assets it purchases from CM (and DM, if it coexists with CM) at $t = 1$. The government clears its liabilities by repaying buyers with the goods. Since buyers are fully competitive, buyers make zero profit just like the self-financing government intervention does.

On the one hand, since the information cost of government is lower than that of the normal buyers, the free entry condition on information investment in DM suggests that only the government survives in asset exchange in DM with information investment. On the other hand, since the government is self-financing and buyers are fully competitive, neither of them gain positive profit from trading in CM. Without loss of generality, we assume only the government trades with sellers in the CM. Therefore in the presence of Assumption 1, only the government

would trade with sellers in either markets in equilibrium. We summarize the key findings in the following proposition.

Proposition 9 (Welfare Effect of Government Asset Purchase Program) *Under Assumption 1, a self-financing government asset purchase program makes high-quality sellers better off while the low quality sellers worse off. More specifically, there exists a cutoff point $\hat{x} \in X = [0, 1]$ such that,*

1. *Sellers with $x \geq \hat{x}$ are better off. Moreover, the net gain strictly increases with their asset quality x .*
2. *Sellers with $x < \hat{x}$ are worse off. Moreover, the net loss weakly increases with their asset quality x .*

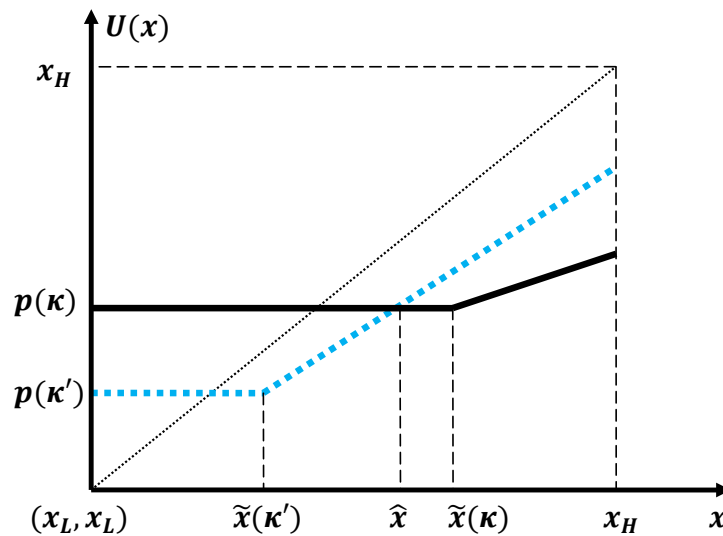


Figure 10: **Government intervention**

The above proposition states that, with Assumption 1, *i.e.*, even though the government has an information advantage than the normal buyers, the government cannot deliver a Pareto improvement for the heterogeneous sellers. The decrease of the information cost by the government encourages it to acquire more information in the DM. As a result, sellers who stay in the DM after the government intervention enjoy a more favorable extensive margin. Moreover, the

favorable market tightness in general equilibrium drives more sellers to switch from the CM to the DM. Therefore the average quality of assets in the CM decreases. In turn, the pooling price in the CM decreases and those who continue to trade in the CM are worse off. Consequently some sellers are better off while the others are worse off. We illustrate the logic and the cut-off value of the above proposition in Figure 10.

4.4 Literature Review

Our paper is most related to Guerrieri and Shimer (2018) and Chang (2017).¹⁸ All the three papers consider two-dimensional private information for asset trading, one is asset payoff while the other is trading motive. See Guerrieri and Shimer (2018) for the comparison between their paper and Chang (2017). Guerrieri and Shimer (2018) show when only asset quality is private information, there exists a unique separating equilibrium. Market illiquidity serves as the separating device. However, when both asset quality and the desire to sell are private information, the economy would be characterized by a unique partial pooling equilibrium. Chang (2017), which also considers private information on asset quality and trading motives with the framework of directed search, delivers similar conclusions. There are several key differences. First of all, our paper adopt different modeling strategy to address private information. Guerrieri and Shimer (2018) use market illiquidity as a signaling device while we adopt costly information acquisition. In our model, CM is subject to adverse selection due to private information on asset's common and private values. Meanwhile, buyers could reduce information asymmetry from two to one dimension and then launch optimal contract to sellers self-selecting into DM. Secondly, the sub-markets with competitive search share very similar market structure in their papers. In contrast, our model offers a framework with endogenous coexistence of CM and DM, two kinds of markets with quite different characteristics. Another related paper is Lester, Shourideh, Venkateswaran and Zetlin-Jones (2019, LSVZ thereafter). Both LSVZ (2019) and our paper analyze the positive and normative implications of screening and adverse selection in frictional markets. Moreover, both of us emphasize that addressing the effects of adverse selection calls for controlling for market structure. The main difference is that LSVZ (2019) demonstrates the intriguing interaction between adverse selection, screening, and imperfect

¹⁸Our paper is also related to a recently minted working paper by Wang (2019). Based on Geromichalos and Herrenbrueck (2016), Wang (2019) considers the sequential trade in frictional asset market, goods market and centralized markets. The key difference is that we consider endogenous coexistence of centralized and decentralized markets while Wang (2009) focuses on the sequential trade in CM and DM, as in Lagos and Wright (2005) and Geromichalos and Herrenbrueck (2016).

competition, while our paper focuses on the endogenous coexistence of exchange and OTC markets.

Pagnotta and Phillipon (2018) also explore market coexistence, but they are engaged in the market fragmentation on trading in organized exchanges with different trading speed. For theory, see Hall and Rust (2003), Miao (2006) and Bolton, Santos and Scheinkman (2016) among others. For empirics, Biais and Green (2019) document the secular migration of corporate-bond trading from CM to DM in the past century. Moreover, as shown in Harris (2003), equity trading has also recently become less centralized. In addition to the literature on market coexistence, our paper is also related to the literature on the liquidity effect of information frictions. Earlier theory include Glosten and Milgrom (1985), Kyle (1985) and Williamson and Wright (1994) among others. Recent burgeoning literature mainly consists of Bolton, Santos and Scheinkman (2011), Kim (2012), Lester, Postlewaite and Wright (2012), Malherbe (2014), Tirole (2012) for theoretical analysis and Eisfeldt (2004), Kurlat (2013), Bigio (2015), Benhabib, Dong and Wang (2018), Dong, Miao and Wang (2018) for the discussion over business cycles. All of these papers assume a unique price in a competitive centralized market with adverse selection. Moreover, Guerrerri, Shimer and Wright (2010), Guerrieri and Shimer (2014, 2018), Chang (2017), Chiu and Koepl (2016) address the effect of information asymmetry on asset trading with search frictions. Alternatively, Tirole and Farhi (2015) and Andolfatto, Berentsen and Waller (2013) adopt costly information acquisition to address the information asymmetry between a single seller and a single buyer. Similar to classic literature on security design, these two papers suggest information investment could be undue diligence under certain conditions. Security design is a burgeoning field with lots of interesting papers, say, DeMarzo and Duffie (1999), DeMarzo (2005) and Dang, Gorton and Holmström (2010) etc. Since our focus is not on security design, we cannot exhaust all the papers in this literature. Instead, we only focus on information investment, which is also a key issue in this field.

5 Conclusion

We develop a tractable model of strategic selection of venue trading to study why considerable financial assets are traded in both exchange and OTC markets (centralized vs decentralized markets, i.e., CM vs DM, respectively). Private information comprises two dimensions: one is asset payoff, while the other is the liquidity shock of asset sellers. Buyers can either stay uninformed or choose to acquire costly information. If buyers incur no information cost, then

they trade in centralized markets (CM), which is free of search friction but is subject to adverse selection. In contrast, those informed buyers may propose a trading menu different from the pooling price. The bilateral trading between sellers and informed buyers may be subject to search frictions.

We show that the equilibrium of the model can be characterized in closed form. In particular, market coexistence emerges endogenously when the information acquisition cost in DM is over some intermediate range. Then, we conduct comparative statics. We find that as matching efficiency in DM increases and the information cost decreases, more trade migrates from CM with adverse selection to DM with search frictions. This finding is consistent with the secular migration of asset trading from CM to DM documented by Biais and Green (2019). Meanwhile, the endogenous coexistence of CM and DM in our paper suggests that investigating implications of adverse selection requires considering the endogenous market structure. Moreover, we show that reducing informational asymmetry with costly information acquisition may be detrimental to welfare.

We have also extended our model to incorporate institutional investors. We model institutional investors differently from retail investors in that they care about the price impact of their selling orders. We then examine how the increase in the number of institutional investors contributes to market migration. Surprisingly, we find that higher market concentration does not necessarily lead to more trading in the OTC market. The reason is that more institutional investors may serve to crowd out existing investors in DM, pushing them back to CM. Even in the parameter region where increasing market concentration does lead to higher trading volume in DM, we derive empirically testable implications that may differentiate this theory to alternative explanations, such as an increase in matching efficiency.

We close the paper with several possible lines for future research. First, the way that we model institutional investors is to assume an exogenous parameter governing the price impact cost. This modeling approach serves our purpose well as it renders tractability and helps to illustrate our main point. On the other hand, it would be interesting in future works to consider endogenizing this parameter by considering strategic interactions across large institutional investors in an imperfect competitive environment. Second, to neatly model endogenous information acquisition and the emergence of DM, we assume direct trading between sellers and buyers in a finite-horizon model. In real life, however, a large amount of asset trading in DM is dealer-intermediated, say, corporate bonds. To better characterize the trading details in DM, such as the bid-ask spread, it may be worthwhile for us to introduce a dealer between

sellers and buyers in DM. Third, it might be desirable for us to integrate the idea in this paper into a dynamic general equilibrium model. Eisfeldt (2004) and Kurlat (2012), among others, are excellent examples of integrating pooling price with adverse selection into RBC models. As suggested throughout this paper, buyers in our paper undertake an endogenous level of information investment to lessen adverse selection. Furthermore, we have endogenous trading venues for market liquidity. In sum, the RBC model with our story might deliver additional insights for dynamic decisions on real investment and information investment, as well as their interactions with each other.

Appendix

A Proofs

Proof of Proposition 1 and 2: Substituting c_1 and c_2 into the objective function yields

$$\begin{aligned}
 U^S(x, \delta) &= \max_{a \in \{0,1\}} \left\{ \max \left\{ \frac{m(b,s)}{s} \eta x, p(x) \right\} a + \delta \left[a \mathbf{1}_{\left\{ \frac{m(b,s)}{s} \eta x > p(x) \right\}} \left(1 - \frac{m(b,s)}{s} \right) x + (1-a)x \right] \right\} \\
 &= \begin{cases} \max_{a \in \{0,1\}} \left\{ \max \left\{ \frac{m(b,s)}{s} \eta x, p(x) \right\} a \right\}, & \delta = 0 \\ \max_{a \in \{0,1\}} \left\{ \max \left\{ \frac{m(b,s)}{s} \eta x, p(x) \right\} a + a \mathbf{1}_{\left\{ \frac{m(b,s)}{s} \eta x > p(x) \right\}} \left(1 - \frac{m(b,s)}{s} \right) x + (1-a)x \right\}, & \delta = 1 \end{cases}
 \end{aligned}$$

As a result, when $\delta = 0$, $a^* = 1$, *i.e.*, investors with preference shock have to sell the claim of their projects. Investors with $\delta = 1$, however, could either participate in centralized or decentralized market ($a = 1$) or simply wait till $t = 2$ ($a = 0$). However, the above optimization implies that investors would never try centralized market due to search friction and bargaining.

First of all, competitive buyers set $p(x) = x$ in complete information. In this scenario, $p(x) > \frac{m(b,s)}{s} \eta x$ for all sellers- $(x, \delta = 0)$ and thus they trade in centralized market. Moreover, sellers- $(x, \delta = 1)$ would be indifferent between selling in centralized market at $t = 1$ and waiting till $t = 2$.

Secondly, in the presence of information asymmetry, $p(x) = p$ for all sellers pooling in centralized market. On one hand, for sellers with $\delta = 0$, if decentralized market does not exist, their only choice is the centralized market. If the decentralized market exists, however, they would compare $\frac{m(b,s)}{s} \eta x$ with p . Furthermore, if $\frac{m(b,s)}{s} \eta x_1 > p$, we would also have $\frac{m(b,s)}{s} \eta x_2 > p$ provided $x_2 > x_1$. Thus there may exist a cut-off point \tilde{x} on the choice of trading venues. If $\tilde{x} \in (x_L, x_H)$, then $\frac{m(b,s)}{s} \eta \tilde{x} = p$ holds by definition. On the other hand, for sellers with $\delta = 1$, as argued above, they would never consider trading in decentralized market even though it would be available. Instead, they simply compare p and x . As a result, those with $x < p$ would sell their asset claims in the centralized market at $t = 1$ while those with $x \geq p$ would enter either markets and wait till $t = 2$.

Finally, based the above two pieces of observation, we have

$$\begin{aligned}
 U^s(x, \delta) &= \begin{cases} p & \text{if } \delta = 0 \text{ and } x \leq \tilde{x} \\ \frac{x}{\tilde{x}} \cdot p & \text{if } \delta = 0 \text{ and } x > \tilde{x} \\ p & \text{if } \delta = 1 \text{ and } x \leq p \\ x & \text{if } \delta = 0 \text{ and } x \leq \tilde{x} \end{cases} \\
 &= \max \left\{ \frac{x}{p + (\tilde{x} - p) \cdot \mathbf{1}_{\{\delta=0\}}}, 1 \right\} \cdot p
 \end{aligned}$$

Proof of Corollary 1: It is immediately obtained by using Proposition 1 and 2.

Proof of Lemma 1: The results in the general case in proved as below.

First of all, we show that $p \leq \tilde{x}$. Eq. (3) suggests that

$$\begin{aligned}
 p &= \frac{\pi F(\tilde{x}) \mathbb{E}(x|x \leq \tilde{x}) + (1 - \pi) F(p) \mathbb{E}(x|x \leq p)}{\pi F(\tilde{x}) + (1 - \pi) F(p)} \\
 &= \frac{\pi \int_{x_L}^{\tilde{x}} x dF(x) + (1 - \pi) \int_{x_L}^p x dF(x)}{\pi F(\tilde{x}) + (1 - \pi) F(p)} \\
 &\leq \frac{\pi \int_{x_L}^{\tilde{x}} \tilde{x} dF(x) + (1 - \pi) \int_{x_L}^p p dF(x)}{\pi F(\tilde{x}) + (1 - \pi) F(p)} \\
 &= \frac{\pi \tilde{x} F(\tilde{x}) + (1 - \pi) p F(p)}{\pi F(\tilde{x}) + (1 - \pi) F(p)},
 \end{aligned}$$

where the inequality strictly holds iff $x > x_L$. Thus we have

$$p \leq \frac{\pi \tilde{x} F(\tilde{x}) + (1 - \pi) p F(p)}{\pi F(\tilde{x}) + (1 - \pi) F(p)}.$$

Multiplying both side of this inequality with $\pi F(\tilde{x}) + (1 - \pi) F(p)$ and rearranging then yields $p \leq \tilde{x}$, where the equality holds iff $\tilde{x} = x_L (= p)$.

Secondly, Eq. (3) can be rewritten as

$$G(p, \tilde{x}, \pi) \equiv \pi \int_{x_L}^{\tilde{x}} x dF(x) + (1 - \pi) \int_{x_L}^p x dF(x) - \pi p F(\tilde{x}) - (1 - \pi) p F(p) = 0.$$

Thus we have

$$\begin{aligned}
 G_p &\equiv \frac{\partial G}{\partial p} = -[\pi F(\tilde{x}) + (1 - \pi) F(p)] < 0 \\
 G_{\tilde{x}} &\equiv \frac{\partial G}{\partial \tilde{x}} = \pi(\tilde{x} - p) f(\tilde{x}) > 0
 \end{aligned}$$

According to Implicit Function Theorem, we have

$$\frac{dp}{d\tilde{x}} = -\frac{G_{\tilde{x}}}{G_p} \Rightarrow 0.$$

Thus we can denote the above result as $p = P_{AS}(\tilde{x}, \pi)$, which is an increasing function of \tilde{x} . Furthermore, since $\tilde{x} \geq x_L$, we immediately have $p \geq x_L$. When $\tilde{x} = x_L$, Eq. (3) is reduced as follows.

$$p = \frac{\int_{x_L}^p x dF(x)}{F(p)} = \mathbb{E}(x|x \leq p),$$

which is a classic problem of adverse selection by Akerlof (1970) and the unique solution is $p = x_L$. As a result, $P_{AS}(\tilde{x} = x_L) = x_L$ and thus $p \geq x_L$. So far we finish the proof that $x_L \leq p \leq \tilde{x}$, where both inequality strictly holds if $\tilde{x} > x_L$.

Moreover, we have

$$\frac{\partial G}{\partial \pi} = \left[\int_{x_L}^{\tilde{x}} x dF(x) - pF(\tilde{x}) \right] - \left[\int_{x_L}^p x dF(x) - pF(p) \right]$$

Define $H(a; p) \equiv \int_{x_L}^a x dF(x) - pF(a)$. Then we have $\frac{\partial H}{\partial a} = (a - p) f(a)$ and thus $H(a; p)$ increases with a when $a > p$. Since $\tilde{x} > p$, we have

$$G_\pi \equiv \frac{\partial G}{\partial \pi} = H(\tilde{x}; p) - H(p; p) > 0,$$

which in turn, by using Implicit Function Theorem again, implies that

$$\frac{dp}{d\pi} = -\frac{G_\pi}{G_p} > 0.$$

Denote $p = P_{AS}(\tilde{x}, \pi)$. Then we know that $p \leq P_{AS}(\tilde{x}, \pi = 1) = \mathbb{E}(x|x \leq \tilde{x}) \leq \mathbb{E}(x|x \leq x_H)$. Finally, when $\pi = 0$, Eq. (3) is reduced to

$$p = \frac{\int_{x_L}^p x dF(x)}{F(p)} = \mathbb{E}(x|x \leq p),$$

which has been discussed above in the case when $\tilde{x} = x_L$. The only solution is $p = P_{AS}(\tilde{x}, \pi = 0) = x_L$ and CM totally collapses.

Finally, when $x \stackrel{U}{\sim} X [x_L, x_H] = [0, 1]$, we have

$$F(x) = \begin{cases} 0 & \text{if } x < x_L \\ \frac{x-x_L}{x_H-x_L} = x & \text{if } x_L \leq x \leq x_H \\ 1 & \text{if } x > x_H \end{cases}.$$

Substituting $F(x)$ into Eq. (3) and making some algebraic manipulation yields Eq. (4).

Proof of Lemma 2: We immediately obtain the results by combining the free entry condition in Section 2.5 with Cobb-Douglas matching function.

Proof of Proposition 3: Combining Proposition 2, Lemma 1, Lemma 2 yields the closed-form solutions in Proposition 3.

Proof of Proposition 4, Proposition 5, Proposition 6 and Corollary 2: With some algebraic manipulation, we can obtain the results as we did for proofs in the baseline model.

Proof of Proposition 7: The proof is similar to that for Lemma 2, and thus omitted here.

Proof of Lemma 3 and Proposition 8: The first part is proved as below. To ease illustration while preserving the key insights, we have assumed that information cost κ is low enough such that $b > s$ is always true in equilibrium. In turn, we have $\frac{m(b,s)}{s} = \lambda \in (0, 1)$, a constant. This would help us focus on characterizing optimal contract by buyers. We break down the proof into the following steps.

First of all, since sellers could always sell their assets at price p in CM and $\delta \in [0, 1]$, buyers in DM would have no customers if $U(x, \delta) < p$. Meanwhile, to recover information cost, buyers in DM ex ante would never accept sellers with $x < p$.

Secondly, for seller- (x, δ) self-selecting into DM and is allowed to trade with buyers there, denote $\tilde{\delta}(x) = \min\{\frac{p}{x}, 1\} = \frac{p}{x}$. Since Then we can check that $\underline{\delta}(x) \leq \tilde{\delta}(x) \leq \bar{\delta}(x)$, where $\underline{\delta}(x)$ and $\bar{\delta}(x)$ are characterized in the proof of Lemma 1. For each x , buyers launch direct mechanism for two groups respectively. One is $\delta \in \Delta_1 = [\underline{\delta}(x), \tilde{\delta}(x)]$ while the other group is $\delta \in \Delta_2 = [\tilde{\delta}(x), \bar{\delta}(x)]$. On one hand, for each group, buyers make sure *IR* and *IC* conditions are satisfied. On the other hand, buyers have to make sure sellers in group $\Delta_1 \cup \Delta_2$ would have no incentive to deviate the other group. After all, even though x is verifiable after buyers incur information cost, δ is still unobservable. As a result, incentive compatibility of not deviating to another group has to be additionally taken into account. In the next two pieces of analysis, we first solve the within-group contract and then go to discussion of *IC* on across-group.

Buyer's objective function for group Δ_1 is

$$\Pi_B(x)|_{\Delta_1} \equiv \max_{\{q(x,\delta) \in [0,1], \tau(x,\delta) \in [0,\infty)\}} \left\{ \int_{\underline{\delta}(x)}^{\tilde{\delta}(x)} [-\tau(x, \delta) + q(x, \delta) \cdot x] \right\}.$$

Meanwhile, for group with $\delta \in \Delta_1$, the outside option is simplified as $V(x, \delta, p) \equiv \delta x + \frac{1}{\lambda} \max\{p - \delta x, 0\} = \frac{p}{\lambda} - (\frac{1}{\lambda} - 1) \delta x$. That is, for sellers in this group, the outside option decreases with δ . Following Maggi and Rodriguez-Clare (1995), among others, we define

$\Upsilon(x, \delta) = U(x, \delta) - V(x, \delta, p)$. Envelope Theorem suggests

$$\frac{\partial \Upsilon}{\partial \delta} = \left[\frac{1}{\lambda} - q(x, \delta) \right] \cdot x.$$

Thus

$$[1 - q(x, \delta)] \delta x + \tau(x, \delta) - \left[\frac{p}{\lambda} - \left(\frac{1}{\lambda} - 1 \right) \delta x \right] = \int_{\underline{\delta}(x)}^{\delta} \left[\frac{1}{\lambda} - q(x, \delta') \right] x d\delta'.$$

Expressing the above equation for $\tau(x, \delta)$ and substituting it into the buyer's objective function for group Δ_1 mentioned above, we can easily prove that, for group Δ_1 , $q^*(x, \delta)|_{\Delta_1} = 1$. Substituting it into the above equation suggests that $\tau^*(x, \delta)|_{\Delta_1}$ has nothing to do with δ and is thus denoted as $\tau^*(x)|_{\Delta_1}$.

Similarly, we can show that $q^*(x, \delta)|_{\Delta_2} = 1$ and $\tau^*(x, \delta)|_{\Delta_2}$ also has nothing to do with δ and is thus denoted as $\tau^*(x)|_{\Delta_2}$. Finally, to make sure the *IC* condition of across-group is satisfied, we have to make sure $\tau^*(x, \delta)|_{\Delta_1} = \tau^*(x, \delta)|_{\Delta_2} \equiv \tau(x)|_{\Delta_1 \cup \Delta_2} = \tau(x)$. In sum, given $x > p$ and buyers and sellers are matched in DM, the optimal contract would take the form as $\{q^*(x, \delta) = 1, \tau^*(x, \delta) = \tau(x)\}$. It is obvious that $\tau(x) \leq x$ is always held.

In turn, we have $U(x, \delta) = \tau(x)$ and thus

$$\begin{aligned} \underline{\delta}(x) &= \max \left\{ 0, \frac{p - \lambda \cdot \tau(x)}{(1 - \lambda) \cdot x} \right\} \\ \bar{\delta}(x) &= \min \left\{ 1, \frac{\tau(x)}{x} \right\} = \frac{\tau(x)}{x}. \end{aligned}$$

As a recap, buyer's profit function focusing on sellers with x is

$$\Pi_B(x) \equiv \max_{\{q(x, \delta) \in [0, 1], \tau(x, \delta) \in [0, \infty)\}_{\mathbf{Z}_{DM}|x}} \left\{ \int_{\delta \in \mathbf{Z}_{DM}|x} [-\tau(x, \delta) + q(x, \delta) \cdot x] \right\}.$$

Using the optimal contract and cut-off values just obtained above, $\Pi_B(x)$ is refined as below.

$$\Pi_B(x) = \max_{\tau(x, \delta) \in [0, x]} [x - \tau(x)] [G(\bar{\delta}(x)) - G(\underline{\delta}(x))].$$

subject to

$$\begin{aligned} \underline{\delta}(x) &= \max \left\{ 0, \frac{p - \lambda \cdot \tau(x)}{(1 - \lambda) \cdot x} \right\}, \\ \bar{\delta}(x) &= \min \left\{ 1, \frac{\tau(x)}{x} \right\} = \frac{\tau(x)}{x}, \end{aligned}$$

where G denotes the CDF of δ with support $[0, 1]$. If we further assume $\delta \stackrel{U}{\sim} \Delta = [0, 1]$, then we obtain $\tau(x)$ as that in Proposition 5. In turn, we obtain $\underline{\delta}(x)$ and $\bar{\delta}(x)$ as in the second part of this proposition.

Proof of Proposition 9: First, we have market coexistence both before and after government intervention. Moreover, since $\kappa_g = \kappa' < \kappa_b = \kappa$, we know from our previous propositions that $\tilde{x}(\kappa_g) \leq \tilde{x}(\kappa_b)$ and thus $p(\kappa_g) \leq p(\kappa_b)$. Additionally, the decrease of information cost implies a more favorable extensive margin for sellers. Therefore, we know that

$$\begin{aligned} U(\tilde{x}(\kappa_g)) &= p(\kappa_g) \\ &\leq p(\kappa_b) = \frac{m(s(\kappa_b), b(\kappa_b))}{s(\kappa_b)} \eta \tilde{x}(\kappa_b) \\ &\leq \frac{m(s(\kappa_g), b(\kappa_g))}{s(\kappa_g)} \eta \tilde{x}(\kappa_b) = U(\tilde{x}(\kappa_b)). \end{aligned}$$

Since $U(x)$ increases with x , there exists a cut-off point $\hat{x} \in (\tilde{x}(\kappa_g), \tilde{x}(\kappa_b))$ such that

$$U(x) \begin{cases} \leq p(\kappa_b) & \text{if } x \leq \hat{x} \\ \geq p(\kappa_b) & \text{if } x \geq \hat{x} \end{cases}.$$

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