(De)centralizing Trade

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We propose a parsimonious model to evaluate the relative merits of centralized and decentralized trade when agents are asymmetrically informed about the value of an asset. In a centralized market, the seller posts one price and buyers simultaneously decide whether to pay this price for the asset. In a decentralized market, the seller sequentially contacts buyers and quotes them potentially different prices. We compare the social efficiency of trade in these two types of market when traders' information sets are independent of the market structure as well as when the acquisition of information by traders is endogenous. (JEL D82, G23, L10)

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1 Introduction

Many assets are traded in decentralized markets. Nowadays, securitized products, interest-rate derivatives, foreign exchange instruments, municipal and corporate bonds are typically traded over the counter, although this was not always the case (Biais and Green 2007, Gensler 2011). In response to the recent financial crisis, many commentators and policy makers have, however, blamed this type of market structure for exacerbating the crisis and suggested significant reforms.[1] This paper attempts to shed light on the popularity of this market structure by investigating the costs and benefits of (de)centralized trade when agents are asymmetrically informed about the value of the assets that need to be traded. Our model identifies specific situations for which decentralized (sequential) trading among agents socially dominates centralized (simultaneous) trading as well as situations for which the opposite is true.

Our model features the owner of an asset who can sell the asset to two potential buyers and realize exogenous, but potentially uncertain, gains to trade. If the market is centralized, the seller posts a price and the two buyers simultaneously decide whether to buy the asset at that price. If the market is decentralized instead, the seller first contacts one buyer and quotes him a price. If the buyer refuses to pay this price, the seller contacts the second buyer (after a costly delay) and quotes him a potentially different price. We first compare the social efficiency of trade in these two types of market assuming that traders' information sets are independent of the market structure. Then, we perform a similar analysis but allow traders to choose how much information to acquire about the value of the asset, based on the market structure.

When delaying trade is costly and the market structure does not change buyers' information acquisition nor the seller's pricing strategies, centralized trade socially dominates decentralized trade. However, we uncover three channels through which decentralizing trade incentivizes traders to change their behaviors in ways that are socially beneficial. First, since centralized trade makes it more likely that a high price quote will be accepted quickly by at least one buyer, there exist situations where a seller would choose an aggressive, socially inefficient trading strategy in a centralized market, but would prefer a more conservative, socially efficient trading strategy in a decentralized market. Second, by being able to quote different prices to different buyers in a decentralized market, the seller may then price discriminate buyers based on their private information and increase the probability that the asset ends up in the hands of its most efficient holder.

[1] For specific examples, see "Implementing the Dodd-Frank Act", a speech given by U.S. CFTC's chairman Gary Gensler in January 2011, "Comparing G-20 Reform of the Over-the-Counter Derivatives Markets", a Congressional Report prepared by James K. Jackson and Rena S. Miller in February 2013, or "Canadian regulators push toward more transparency, oversight for huge fixed income market" by Barbara Shecter in the September 17, 2015 issue of the Financial Post.

Third, since centralized trade typically provides weaker incentives to acquire information, decentralized markets tend to socially dominate centralized markets when information acquisition is socially valuable. The opposite is, however, true when information only benefits a trader's rent-seeking ability in a zero-sum trading game, thus impeding trade due to adverse selection concerns.

Furthermore, our model reveals how the costly delays associated with decentralized trade can have a socially beneficial impact by reducing a seller's incentive to quote aggressive prices. When traders have time-sensitive trading needs, "opaque" decentralized markets may thus socially dominate transparent decentralized markets or even centralized markets, provided that traders are asymmetrically informed, contrasting with the predictions of search-based models where traders are symmetrically informed like in Duffie, Gârleanu, and Pedersen (2005).

Our paper differs from the related market microstructure literature in several ways. First, our model focuses on the role of information asymmetries, rather than liquidity externalities (Pagano 1989), monopoly power and order size (Viswanathan and Wang 2002), or counterparty risk (Duffie and Zhu 2011, Acharya and Bisin 2014), in determining the costs and benefits of (de)centralized trade. Second, unlike in Grossman (1992) where it is assumed that the upstairs (i.e., decentralized) market features dealers who possess information about unexpressed demand that is not available to the traders in the downstairs (i.e., centralized) market, our analysis compares the efficiency of decentralized and centralized markets both when traders' information is exogenous and stays the same across market structures and when traders' information is endogenous to the market structure. The fact that we focus on the social efficiency of trade also distinguishes our paper from Kirilenko (2000) who studies the choice of a trading arrangement (one-shot batch auction vs. continuous dealer market) by an authority trying to maximize price discovery in the context of emerging foreign exchange markets.

The idea that, in our model, decentralized markets allow traders to reach various potential counterparties in a sequential manner while centralized markets allow traders to reach all potential counterparties simultaneously relates our paper to Seppi (1990) and Zhu (2012). Seppi (1990) studies the existence of dynamic equilibria where a trader prefers to submit a large order to a dealer than a sequence of small market orders to an exchange. Central to this result is the assumption that a dealer knows the identity of his traders, which allows for the implementation of dynamic commitments not possible in anonymous centralized markets. Like us, Zhu (2012) models decentralized trading as a sequence of offers to multiple counterparties. However, his focus is on the impact that repeated contacts have on the dynamics of trade. In our model, each potential counterparty can only be contacted once, hence, the “ringing phone curse” that is central in Zhu (2012) plays no role in our model. Moreover, unlike in Seppi (1990) and Zhu (2012) where traders’ information is exogenously given, our paper studies how traders’ incentives to acquire information depend on the market structure, and how this endogeneity of information affects social efficiency.

2 Model

The owner of an asset considers selling it to one of two potential buyers. Each agent i values the asset as the sum of two components: $v + b_i$. The common value component v matters to all traders and is distributed as $v \in \{\bar{v} - \sigma_v, \bar{v} + \sigma_v\}$ with equal probabilities. The private value component b_i is independent for each trader i. It is assumed to be 0 for the seller while it takes a value $b_i \in \{\Delta - \sigma_b, \Delta + \sigma_b\}$ with equal probabilities for each buyer i. In expectation, moving the asset from the seller to a buyer creates a social surplus of $E[b_i] = \Delta > 0$.

Agents are asymmetrically informed about the value of the asset. To eliminate the possibility multiplicity of equilibria due to potential signaling games, we assume the seller of the asset only knows the ex-ante distributions for v and b_i. Each buyer i is, however, assumed to collect private information about his own realization of v_i with probability $\pi \in (0, 1)$.

Throughout the paper, we will compare the social welfare and the owner’s profit from selling the asset in two types of market. In a centralized market, the seller posts a price that can be accepted by any of the two potential buyers. If both buyers accept to pay the posted price, then one buyer is randomly chosen to participate in the trade. In a decentralized market, the seller quotes a price to the first buyer. If this price is accepted, trade occurs at that price, but if it is rejected, the seller moves on and quotes a potentially different price to the second buyer. If trade occurs in the second round of trade, the delay reduces the surplus from trade to ρb_i, where $\rho \leq 1$. The reduction in surplus of $(1 - \rho)b_i$ captures the traders’ impatience, liquidity concerns, or any search friction that makes locating a second buyer costly. If both rounds of trade fail, the seller is confined to keeping the asset and the surplus from trade is lost.

Assuming sequential ultimatum offers in the decentralized market simplifies the analysis of equilibrium bidding strategies and is consistent with the characterization of inter-dealer trading in financial markets by Viswanathan and Wang (2004, p.3) as “very quick interactions”. Ultimatum offers are also consistent with how Duffie (2012, p.2) describes the typical negotiation process in OTC markets and the notion that each OTC dealer tries to maintain "a reputation for standing firm on its original quotes."

In this paper, we focus on two specific cases: one where σ_b is large and $\sigma_v = 0$ and one where σ_v is large and $\sigma_b = 0$. Focusing on these two cases allows us to highlight how uncertainty in private valuations b_i and in the common value v differently affect the optimality of a market structure. An appropriate benchmark case in our model is one where $\sigma_v \to 0$ and $\sigma_b \to 0$. In such case, both buyers are always willing to pay at least $\bar{v} - \sigma_v + \Delta - \sigma_b$ for the asset. The seller can quote higher prices than $p = \bar{v} - \sigma_v + \Delta - \sigma_b$ but the upside of collecting these prices is at most $\sigma_v + \sigma_b$, which is too small to justify the discrete drops in the probability of acceptance and in the surplus from trade. The seller thus finds it optimal to quote a price $p = \bar{v} - \sigma_v + \Delta - \sigma_b$ that is accepted with probability 1, regardless of whether he is contacting the two bidders simultaneously (i.e., in a centralized market) or sequentially (i.e., in a decentralized market). The surplus generated by trade is then Δ in both types of market.

3 Asymmetric Information about Private Values

In this section, we study the case where σ_v is small (i.e., $\sigma_v = 0$) and equilibrium trading outcomes are driven by the mean and the volatility of buyers' private valuations (i.e., Δ and σ_b). This analysis will be informative about the optimal market structure for securities like highly rated municipal and corporate bonds or Treasury securities. Moreover, we assume that the uncertainty in private valuations is large enough to have $\sigma_b \geq \Delta$, meaning that trading the asset from the seller to the buyer does not always create a social surplus.

3.1 Centralized Market

We first consider the situation where the seller trades through a centralized venue by posting a price that can be accepted by any of the two buyers. If both buyers are willing to pay the posted price, then one of them is randomly chosen to participate in the trade.

The highest price the seller can post that has a positive probability of being accepted is $p = \bar{v} + \Delta + \sigma_b$. This price is accepted only if at least one of the buyers is informed and values the asset at $v_i = \bar{v} + \Delta + \sigma_b$. This occurs with probability $\frac{3}{4}\pi^2 + \pi(1 - \pi)$. By quoting this price, the seller collects an expected payoff of:

$$\left[\frac{3}{4}\pi^2+\pi(1-\pi)\right](\bar{v}+\Delta+\sigma_b)+\left[1-\frac{3}{4}\pi^2-\pi(1-\pi)\right]\bar{v}=\bar{v}+\pi\left(1-\frac{\pi}{4}\right)(\Delta+\sigma_b). \tag{1}$$

The seller may also consider quoting a price $p=\bar{v}+\Delta$, which is low enough to be accepted by buyers who do not have private information about their v_i. An informed buyer accepts a price $p=\bar{v}+\Delta$ only when he knows that his own $v_i=\bar{v}+\Delta+\sigma_b$. Since $\sigma_v=0$ and buyers only condition their trading decision on a private value component, each buyer does not have to protect himself against the private information of competing buyers. Later, when we look at cases where σ_v is large compared to σ_b, adverse selection among buyers will affect the trading strategies of the traders in our model. By quoting a price $p=\bar{v}+\Delta$, the seller collects an expected payoff of:

$$\left[\frac{3}{4}\pi^2+2\pi(1-\pi)+(1-\pi)^2\right](\bar{v}+\Delta)+\left[1-\frac{3}{4}\pi^2-2\pi(1-\pi)-(1-\pi)^2\right]\bar{v}=\bar{v}+\left(1-\frac{\pi^2}{4}\right)\Delta. \tag{2}$$

Finally, the seller may consider quoting a price $p=\bar{v}+\Delta-\sigma_b$, which is accepted by all buyers, but quoting this price is dominated by keeping the asset which in expectation is worth $\bar{v}$ to him. Keeping the asset is, however, dominated by quoting either $p=\bar{v}+\Delta+\sigma_b$ or $p=\bar{v}+\Delta$.

The seller thus quotes the price $p=\bar{v}+\Delta$ whenever:

$$\begin{aligned}\bar{v}+\left(1-\frac{\pi^2}{4}\right) &\geq \bar{v}+\pi\left(1-\frac{\pi}{4}\right)(\Delta+\sigma_b)\Delta\\ \Leftrightarrow\frac{\Delta}{\sigma_b} &\geq \left(1-\frac{\pi}{4}\right)\left(\frac{\pi}{1-\pi}\right),\end{aligned} \tag{3}$$

and in such case, the social surplus from trade is $\left(1+\frac{\pi}{2}\right)\left[\left(1-\frac{\pi}{2}\right)\Delta+\frac{\pi}{2}\sigma_b\right]$. Otherwise, the seller quotes the high price $p=\bar{v}+\Delta+\sigma_b$ and the social surplus from trade is $\pi\left(1-\frac{\pi}{4}\right)(\Delta+\sigma_b)$. Since the buyers' valuations are uncertain, the seller must make a price concession to encourage less informed traders to buy the asset. When the expected surplus from trade (Δ) is large, the seller is willing to make such a price concession, but when the uncertainty in the surplus from trade (σ_b) is large, the price concession needed is too high and the seller prefers to quote a higher price, even though it means that the surplus from trade is destroyed with a higher probability.

From a social standpoint, the surplus from trade is greater if the seller quotes the low price $p=\bar{v}+\Delta$

than the high price $p = \bar{v} + \Delta + \sigma_b$ whenever:

$$\begin{aligned} \left(1 + \frac{\pi}{2}\right)\left[\left(1 - \frac{\pi}{2}\right)\Delta + \frac{\pi}{2}\sigma_b\right] &> \pi\left(1 - \frac{\pi}{4}\right)(\Delta + \sigma_b) \\ \Leftrightarrow \frac{\Delta}{\sigma_b} &> \frac{1}{2}\left(\frac{\pi}{1-\pi}\right). \end{aligned} \tag{4}$$

Hence, in the region where $\frac{1}{2}\left(\frac{\pi}{1-\pi}\right) < \frac{\Delta}{\sigma_b} < \left(1 - \frac{\pi}{4}\right)\left(\frac{\pi}{1-\pi}\right)$, the seller quotes a socially inefficient, high price.

3.2 Decentralized Market

We now consider the situation where the seller trades through a decentralized venue by quoting a price to the first buyer and if this price is rejected, by quoting a potentially different price to the second buyer. We assume, however, that if trade is realized in the second round of trade, the delay reduces the surplus from trade to ρb_i, where $\rho \leq 1$. The reduction in surplus captures the traders' impatience, liquidity concerns, or any search friction that makes locating a second buyer costly. Finally, if both rounds of trade fail, the seller is confined to keeping the asset and the surplus from trade is lost.

Since $\sigma_v = 0$ in this section, a rejection in the first round of trade is only informative about the private valuation of the first buyer, or about the fact that he is uninformed. The seller then quotes the second buyer one of the following prices: $p = \bar{v} + \rho(\Delta + \sigma_b)$, $p = \bar{v} + \rho\Delta$, or $p = \bar{v} + \rho(\Delta - \sigma_b)$.

By quoting the high price $p = \bar{v} + \rho(\Delta + \sigma_b)$, the seller collects an expected payoff of:

$$\frac{\pi}{2}(\bar{v} + \rho\Delta + \rho\sigma_b) + \left(1 - \frac{\pi}{2}\right)\bar{v} = \bar{v} + \frac{\pi}{2}(\rho\Delta + \rho\sigma_b). \tag{5}$$

The seller may instead quote a price $p = \bar{v} + \rho\Delta$, which is low enough to be accepted by a second buyer who does not have private information about his v_i. By quoting this price, the seller collects an expected payoff of:

$$\left[\frac{\pi}{2} + (1-\pi)\right](\bar{v} + \rho\Delta) + \frac{\pi}{2}\bar{v} = \bar{v} + \left(1 - \frac{\pi}{2}\right)\rho\Delta. \tag{6}$$

Finally, the seller may quote a price $p = \bar{v} + \rho(\Delta - \sigma_b)$, which is always accepted, but quoting this price is dominated by keeping the asset which in expectation is worth $\bar{v}$ to him. Keeping the asset is, however, dominated by quoting the high price $p = \bar{v} + \rho(\Delta + \sigma_b)$. The seller thus quotes the price $p = \bar{v} + \rho\Delta$ in the second round of trade whenever:

$$\begin{aligned}\bar{v} + \left(1 - \frac{\pi}{2}\right)\rho\Delta &\geq \bar{v} + \frac{\pi}{2}(\rho\Delta + \rho\sigma_b) \\ \Leftrightarrow \frac{\Delta}{\sigma_b} &\geq \frac{1}{2}\left(\frac{\pi}{1-\pi}\right),\end{aligned} \tag{7}$$

otherwise he quotes the high price $p = \bar{v} + \rho(\Delta + \sigma_b)$.

When choosing a price to quote to the second buyer, the seller picks the price that maximizes his expected payoff. We denote this maximal payoff from trade in the second round as $\bar{v} + \rho W^*$, where $W^* \equiv \max\{\frac{\pi}{2}(\Delta + \sigma_b), \left(1 - \frac{\pi}{2}\right)\Delta\}$. Knowing that he can collect $\bar{v} + \rho W^*$ if his first-round price is rejected, the seller can quote a price $p = \bar{v} + \Delta + \sigma_b$ to the first buyer and collect:

$$\frac{\pi}{2}(\bar{v} + \Delta + \sigma_b) + \left(1 - \frac{\pi}{2}\right)(\bar{v} + \rho W^*) = \bar{v} + \frac{\pi}{2}(\Delta + \sigma_b) + \left(1 - \frac{\pi}{2}\right)\rho W^*. \tag{8}$$

The seller may instead quote a price $p = \bar{v} + \Delta$ to the first buyer and collect:

$$\left[\frac{\pi}{2} + (1 - \pi)\right](\bar{v} + \Delta) + \frac{\pi}{2}(\bar{v} + \rho W^*) = \bar{v} + \left(1 - \frac{\pi}{2}\right)\Delta + \frac{\pi}{2}\rho W^*. \tag{9}$$

Finally, the seller may quote a price $p = \bar{v} + \Delta - \sigma_b$, which is always accepted, but quoting this price is dominated by keeping the asset which in expectation is worth $\bar{v}$ to him. Keeping the asset is, however, dominated by quoting either $p = \bar{v} + \Delta + \sigma_b$ or $p = \bar{v} + \Delta$.

The seller thus quotes the price $p = \bar{v} + \Delta$ in the first round of trade whenever:

$$\begin{aligned}\bar{v} + \left(1 - \frac{\pi}{2}\right)\Delta + \frac{\pi}{2}\rho W^* &\geq \bar{v} + \frac{\pi}{2}(\Delta + \sigma_b) + \left(1 - \frac{\pi}{2}\right)\rho W^* \\ \Leftrightarrow \frac{\Delta}{\sigma_b} &\geq \frac{\rho W^*}{\sigma_b} + \frac{1}{2}\left(\frac{\pi}{1-\pi}\right),\end{aligned} \tag{10}$$

otherwise he quotes the high price $p = \bar{v} + \Delta + \sigma_b$. Since $W^* > 0$, we know that this inequality is strictly more restrictive than condition (7), which means that if the seller quotes $p = \bar{v} + \Delta$ to the first buyer, he will quote $p = \bar{v} + \rho\Delta$ if he needs to trade with the second buyer.

Overall, we have three possible trading strategies for the seller. The seller quotes $p = \bar{v} + \Delta$ to the first buyer and $p = \bar{v} + \rho\Delta$ to the second buyer when needed whenever:

$$\begin{aligned}\frac{\Delta}{\sigma_b} &\geq \frac{\rho W^*}{\sigma_b} + \frac{1}{2}\left(\frac{\pi}{1-\pi}\right) \\ &= \left(1 - \frac{\pi}{2}\right)\rho\frac{\Delta}{\sigma_b} + \frac{1}{2}\left(\frac{\pi}{1-\pi}\right), \end{aligned} \tag{11}$$

which can be rewritten as:

$$\frac{\Delta}{\sigma_b} \geq \frac{1}{2}\left(\frac{1}{1-\rho+\frac{\rho\pi}{2}}\right)\left(\frac{\pi}{1-\pi}\right). \tag{12}$$

In such case, the social surplus from trade is $\left(1+\frac{\rho\pi}{2}\right)\left[\left(1-\frac{\pi}{2}\right)\Delta + \frac{\pi}{2}\sigma_b\right]$.

The seller quotes $p = \bar{v} + \Delta + \sigma_b$ to the first buyer and $p = \bar{v} + \rho\Delta$ to the second buyer when needed whenever:

$$\frac{1}{2}\left(\frac{\pi}{1-\pi}\right) \leq \frac{\Delta}{\sigma_b} < \frac{1}{2}\left(\frac{1}{1-\rho+\frac{\rho\pi}{2}}\right)\left(\frac{\pi}{1-\pi}\right), \tag{13}$$

and, in such case, the social surplus from trade is $\left[\frac{\pi}{2} + \rho\left(1-\frac{\pi}{2}\right)^2\right]\Delta + \frac{\pi}{2}\left(1+\rho-\frac{\rho\pi}{2}\right)\sigma_b$.

The seller quotes $p = \bar{v} + \Delta + \sigma_b$ to the first buyer and $p = \bar{v} + \rho(\Delta + \sigma_b)$ to the second buyer when needed whenever:

$$\frac{\Delta}{\sigma_b} < \frac{1}{2}\left(\frac{\pi}{1-\pi}\right), \tag{14}$$

and, in such case, the social surplus from trade is $\frac{\pi}{2}\left(1+\rho-\frac{\rho\pi}{2}\right)(\Delta+\sigma_b)$.

3.3 Optimal Market Structure

Now, we compare the social efficiency of trade across the different types of market.

First, suppose that Δ is small enough relative to σ_b that the seller finds it optimal to quote a price $p = \bar{v}+\Delta+\sigma_b$ in the centralized market and prices of $p = \bar{v}+\Delta+\sigma_b$ to the first buyer and $p = \bar{v}+\rho(\Delta+\sigma_b)$ to the second buyer when needed in a decentralized market. For this to be the case, we need:

$$\frac{\Delta}{\sigma_b} < \left(\frac{\pi}{1-\pi}\right)\min\{\left(1-\frac{\pi}{4}\right), \frac{1}{2}\} = \frac{1}{2}\left(\frac{\pi}{1-\pi}\right). \tag{15}$$

If such condition is satisfied, the social surplus created by trade is $\pi\left(1-\frac{\pi}{4}\right)(\Delta+\sigma_b)$ in the centralized market and $\frac{\pi}{2}\left(1+\rho-\frac{\rho\pi}{2}\right)(\Delta+\sigma_b)$ in the decentralized market. The centralized market is socially optimal whenever:

$$\begin{aligned}\pi\left(1-\frac{\pi}{4}\right)(\Delta+\sigma_b) &\geq \frac{\pi}{2}\left(1+\rho-\frac{\rho\pi}{2}\right)(\Delta+\sigma_b)\\ \Leftrightarrow 1-\frac{\pi}{4} &\geq \frac{1}{2}\left(1+\rho-\frac{\rho\pi}{2}\right)\\ \Leftrightarrow 1-\rho &\geq \frac{\pi}{2}(1-\rho), \end{aligned} \tag{16}$$

which always holds and becomes a strict inequality when $\rho < 1$. The centralized market allows the seller to quote the same high price to both buyers instead of first contacting one buyer and then, if needed, contacting a second buyer at a social cost as in the decentralized market. Thus, when the uncertainty in b_i is high relative to Δ and delay is costly, the centralized market socially dominates the decentralized one.

At the other extreme, suppose that Δ is large enough relative to σ_b that the seller finds it optimal to quote a price $p = \bar{v} + \Delta$ in the centralized market and prices of $p = \bar{v} + \Delta$ to the first buyer and $p = \bar{v} + \rho\Delta$ to the second buyer when needed in a decentralized market. For this to be the case, we need:

$$\frac{\Delta}{\sigma_b} \geq \left(\frac{\pi}{1-\pi}\right)\max\{\left(1-\frac{\pi}{4}\right), \frac{1}{2}\left(\frac{1}{1-\rho+\frac{\rho\pi}{2}}\right)\}. \tag{17}$$

If such condition is satisfied, the social surplus created by trade is $\left(1+\frac{\pi}{2}\right)\left[\left(1-\frac{\pi}{2}\right)\Delta + \frac{\pi}{2}\sigma_b\right]$ in the centralized market and $\left(1+\frac{\rho\pi}{2}\right)\left[\left(1-\frac{\pi}{2}\right)\Delta + \frac{\pi}{2}\sigma_b\right]$ in the decentralized market. The centralized market is socially optimal whenever:

$$1+\frac{\pi}{2} \geq 1+\frac{\rho\pi}{2} \tag{18}$$

which always holds and becomes a strict inequality when $\rho < 1$. As in the earlier case, the centralized market allows the seller to quote the same price to both buyers instead of first contacting one buyer and then, if needed, contacting a second buyer at a social cost as in the decentralized market. Thus, when the uncertainty in b_i is low relative to Δ and delay is costly, a centralized market socially dominates a decentralized market.

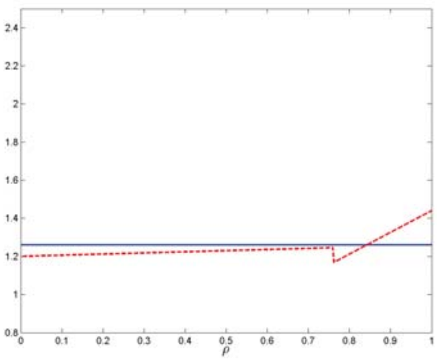
The common feature of the two scenarios above is that the market structure does not change the type of buyers the seller targets with his price quotes. In such cases, simultaneous trade is socially better than sequential trade with a positive probability of a costly delay. Comparing the two types of market, however, yields different implications when we look at intermediate values for Δ, that is, when:

$$\frac{1}{2}\left(\frac{\pi}{1-\pi}\right) \leq \frac{\Delta}{\sigma_b} < \left(\frac{\pi}{1-\pi}\right) \max\{\left(1-\frac{\pi}{4}\right), \frac{1}{2}\left(\frac{1}{1-\rho+\frac{\rho\pi}{2}}\right)\}. \tag{19}$$

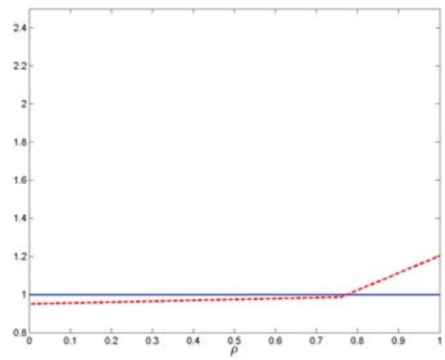
Unlike outside these bounds, we now have instances where decentralized trading socially dominates centralized trading. To see this, we set $\bar{v} = 100$, $\sigma_v = 0$, $\sigma_b = 10$, $\Delta = 1$, and $\pi = 0.1$. In a centralized market, the seller finds it optimal to quote a price $p = 111$ and collect a surplus of 1.0725 rather than quoting a price $p = 101$ and collecting a surplus of 0.9975. The social surplus from trade is then 1.0725 in the centralized market.

The seller's optimal trading strategy in the decentralized market depends on the level of ρ, the discount factor when trade is delayed. In the current parameterization, the seller finds it optimal to quote the low price $p = 100 + \rho$ to the second buyer rather than a high price $p = 100 + 11\rho$, regardless of the value for ρ. When $\rho = 1$, meaning that delay is costless, the seller prefers to quote a price $p = 111$ to the first buyer and collect a surplus of 1.4525 than quoting him a price $p = 101$ and collecting a surplus of 0.9975. The social surplus is then 1.9275 in the decentralized market, which is higher than the surplus in the centralized market. Now when $\rho = 0.5$, the seller still finds it optimal to quote a price $p = 111$ to the first buyer, but since delay is costly, the social surplus from trade drops to 1.23875. Finally, when $\rho = 0$, the seller finds it optimal to quote a price $p = 101$ to the first buyer and collect a surplus of 0.95 rather than quoting a price $p = 111$ and collecting a surplus of 0.55. The social surplus from trade is then 1.45 in the decentralized market, which is higher than the surplus in the centralized market.

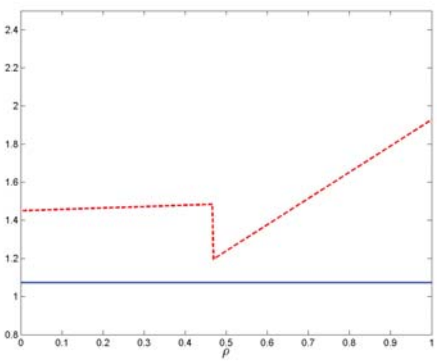
Note that this social surplus is also higher than the social surplus from the case where $\rho = 0.5$, suggesting that "opaque" decentralized markets (i.e., with lower ρ) may, under some circumstances, incentivize traders to behave in more socially efficient ways compared to more transparent decentralized markets or even centralized markets. This social benefit of opacity contrasts with the predictions from Duffie, Gârleanu, and Pedersen (2005), where search frictions unambiguously lower the efficiency of trade. In our model, the seller's trading strategy in the first round of trade depends on the payoff he expects to collect if trade fails and he behaves less aggressively if the surplus available in the second round of trade is low due to a high cost of delay $(1-\rho)b_i$. This response by the seller is absent from Duffie, Gârleanu, and Pedersen (2005) where traders are symmetrically informed and the surplus from trade is split among them using Nash bargaining.



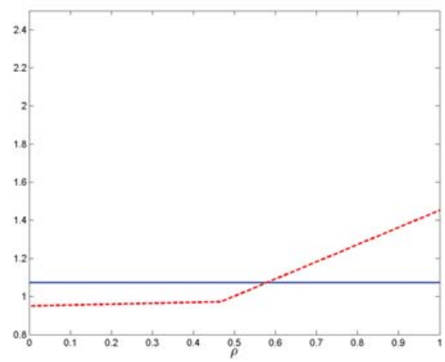
(a) Social surplus for $\sigma_b = 5$.



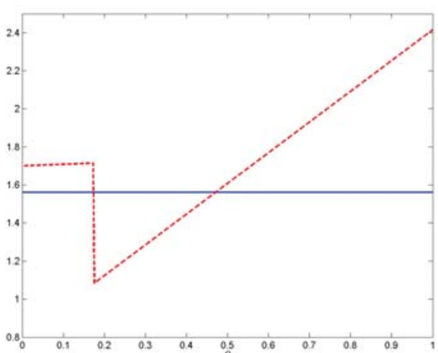
(b) Seller's surplus for $\sigma_b = 5$.



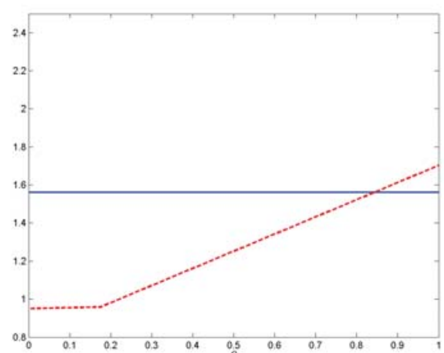
(c) Social surplus for $\sigma_b = 10$.



(d) Seller's surplus for $\sigma_b = 10$.



(e) Social surplus for $\sigma_b = 15$.



(f) Seller's surplus for $\sigma_b = 15$.

Figure 1: **Surplus from trade with uncertain private values.** In these figures, we set $\Delta = 1$, $\sigma_v = 0$, and $\pi = 0.1$ and plot the social surplus from trade and the seller's expected surplus as functions of the discount factor when trade is delayed. The dash line represents the surplus in a decentralized market while the solid line represents the surplus in a centralized market.

This relationship between ρ and the social surplus from trade is more broadly illustrated in Figure 1. Panels (c) and (d) set $\sigma_b = 10$ just as above and show that decentralized trading then socially dominates centralized trading for any value of ρ. When ρ is small, the seller quotes a low price to the first buyer to ensure that trade occurs with a higher probability. This trading strategy helps preserve a higher surplus from trade than centralized trading, where the seller quotes the socially inefficient, high price (see condition (4)). As ρ increases, however, the seller faces stronger incentives to quote the high price to the first buyer, since the surplus from trade available when meeting the second buyer grows with ρ. Once the seller starts quoting the high price to the first buyer, we see a drop in the social surplus from trade, but since enough surplus is created in the second round of trade, decentralized trading still socially dominates centralized trading. As far as the seller is concerned, trading in a decentralized market allows to collect a higher surplus from trade whenever delay is not too costly. Hence, for large values of ρ, the decentralized market dominates the centralized market from the standpoint of the seller and of a social planner.

When we increase the uncertainty in private valuations to $\sigma_b = 15$ (panels (e)-(f)), the seller still finds it optimal to quote the low price to the second buyer when needed in the decentralized market. As earlier, the decentralized market generates a higher social surplus and a higher seller's surplus than a centralized market as long as delay is not too costly, that is, ρ is high enough. Decentralized trading is, however, socially dominated by centralized trading when ρ is moderate. That is due to the fact that the surplus from trade that is available in the second round of trade (i.e., ρb_i) is small compared to the benefit of quoting a price to both buyers simultaneously, that is, without a costly delay. When ρ is small, the seller switches to quoting a low price to the first buyer, which ensures that trade occurs with a high enough probability to socially dominate centralized trade.

Finally, when we decrease the uncertainty in private valuations to $\sigma_b = 5$ (panels (a)-(b)), the seller quotes the low price in the centralized market. Since this price is socially optimal in the centralized market (see condition (4)), it becomes harder for decentralized trade to socially dominate centralized trade. Yet, a decentralized market can socially dominate a centralized market when ρ is high enough and delay is not too costly.

4 Information Acquisition with Uncertain Private Values

We now endogenize the probabilities at which buyers obtain private information about their own valuation of the asset, that is, buyer i can incur a cost $\frac{c}{2}\pi_i^2$ in order to learn his own v_i with probability π_i.

4.1 Centralized Market

In order to analyze the information acquisition choice of buyers, we first need to generalize our earlier derivations for the seller's trading behavior and the resulting allocation of surplus for asymmetric values of π_i.

As earlier, the seller considers quoting a high price $p = \bar{v} + \Delta + \sigma_b$ or a low price $p = \bar{v} + \Delta$. The high price is accepted with a probability:

$$\frac{3}{4}\pi_1\pi_2 + \frac{1}{2}\pi_1(1-\pi_2) + \frac{1}{2}\pi_2(1-\pi_1) = \frac{1}{2}\left(\pi_1 + \pi_2 - \frac{1}{2}\pi_1\pi_2\right). \tag{20}$$

Thus, by quoting the high price $p = \bar{v} + \Delta + \sigma_b$, the seller collects an expected payoff of:

$$\begin{aligned} & \frac{1}{2}\left(\pi_1 + \pi_2 - \frac{1}{2}\pi_1\pi_2\right)(\bar{v} + \Delta + \sigma_b) + \left[1 - \frac{1}{2}\left(\pi_1 + \pi_2 - \frac{1}{2}\pi_1\pi_2\right)\right]\bar{v} \\ = \; & \bar{v} + \frac{1}{2}\left(\pi_1 + \pi_2 - \frac{1}{2}\pi_1\pi_2\right)(\Delta + \sigma_b). \end{aligned} \tag{21}$$

If the seller quotes the low price $p = \bar{v} + \Delta$ instead, this price is only rejected when both buyers are informed and value the asset at $v_i = \bar{v} + \Delta - \sigma_b$, which occurs with probability $\frac{1}{4}\pi_1\pi_2$. The seller then collects an expected payoff of:

$$\left(1 - \frac{1}{4}\pi_1\pi_2\right)(\bar{v} + \Delta) + \frac{1}{4}\pi_1\pi_2\bar{v} = \bar{v} + \left(1 - \frac{1}{4}\pi_1\pi_2\right)\Delta. \tag{22}$$

The seller thus quotes the high price $p = \bar{v} + \Delta + \sigma_b$ whenever:

$$\begin{aligned} \bar{v} + \frac{1}{2}\left(\pi_1 + \pi_2 - \frac{1}{2}\pi_1\pi_2\right)(\Delta + \sigma_b) \quad &> \quad \bar{v} + \left(1 - \frac{1}{4}\pi_1\pi_2\right)\Delta \\ \Leftrightarrow \frac{\Delta}{\sigma_b} \quad &< \quad \frac{\pi_1 + \pi_2 - \frac{1}{2}\pi_1\pi_2}{2 - \pi_1 - \pi_2}. \end{aligned} \tag{23}$$

If that is the case, the social surplus from trade is $\frac{1}{2}\left(\pi_1 + \pi_2 - \frac{1}{2}\pi_1\pi_2\right)(\Delta + \sigma_b)$ as both buyers collect zero surplus. Otherwise, the seller quotes the lower price $p = \bar{v} + \Delta$ and the social surplus from trade is $\left(1 - \frac{1}{4}\pi_1\pi_2\right)\Delta + \frac{1}{4}\left(\pi_1 + \pi_2 + \pi_1\pi_2\right)\sigma_b$. Buyer i's surplus is then:

$$\frac{\pi_i}{2}\left((1-\pi_j)\frac{1}{2} + \pi_j\left(\frac{1}{2}\frac{1}{2} + \frac{1}{2}\right)\right)\sigma_b = \frac{\pi_i}{4}\left(1 + \frac{\pi_j}{2}\right)\sigma_b. \tag{24}$$

We restrict our attention to equilibria where the seller picks a pure-strategy price quote and buyers' information acquisition strategies are symmetric. Right away, we can rule out equilibria where π_i and π_j are high enough for the seller to always quote the high price. In such case, buyers would be better off not acquiring information and the high price would always be rejected. We can also rule out equilibria where buyers never acquire information since the marginal cost of acquiring information is $c\pi_i$ and increasing π_i is strictly profitable when the seller quotes the low price. Hence, in equilibrium, the seller must quote the low price $p = \bar{v} + \sigma_b$ and both buyers must choose $\pi_i \in (0, 1)$.

Conditional on the seller choosing the low price $p = \bar{v} + \Delta$, buyer i chooses π_i to maximize:

$$\frac{\pi_i}{4}\left(1 + \frac{\pi_j}{2}\right)\sigma_b - \frac{c}{2}\pi_i^2. \tag{25}$$

Given an interior optimum $\pi_i \in (0, 1)$, we obtain:

$$\pi_i^*(\pi_j) = \left(1 + \frac{\pi_j}{2}\right)\frac{\sigma_b}{4c}, \tag{26}$$

which by symmetry implies:

$$\pi^* = \frac{\sigma_b}{\left(4c - \frac{\sigma_b}{2}\right)}. \tag{27}$$

For this π^* to be sustained in equilibrium, it must be that the seller optimally quotes the low price, which we know from condition (3) only occurs when:

$$\frac{\Delta}{\sigma_b} \geq \left(1 - \frac{\pi^*}{4}\right)\left(\frac{\pi^*}{1 - \pi^*}\right). \tag{28}$$

4.2 Decentralized Market

As was the case with exogenous information, a rejection in the first round of decentralized trade is only informative about the private valuation of the first buyer, or about the fact that he is uninformed. Hence, the seller quotes the second buyer ($i = 2$) either $p = \bar{v} + \rho(\Delta + \sigma_b)$ or $p = \bar{v} + \rho\Delta$. We can use the reasoning from the case with exogenous information and replace π by π_2 in condition (7) in order to conclude that the seller quotes the low price $p = \bar{v} + \rho\Delta$ whenever:

$$\frac{\Delta}{\sigma_b} \geq \frac{1}{2}\left(\frac{\pi_2}{1-\pi_2}\right), \tag{29}$$

otherwise he quotes the high price $p = \bar{v} + \rho(\Delta + \sigma_b)$.

We now denote the maximal payoff from trade in the second round as $\bar{v} + \rho W^*(\pi_2)$, where $W^*(\pi_2) \equiv \max\{\frac{\pi_2}{2}(\Delta + \sigma_b), \left(1 - \frac{\pi_2}{2}\right)\Delta\}$. The seller must choose whether to quote $p = \bar{v} + \Delta + \sigma_b$ or $p = \bar{v} + \Delta$ to the first buyer ($i = 1$), knowing that he can collect $\bar{v} + \rho W^*(\pi_2)$ if his first-round price is rejected. The seller thus quotes the low price $p = \bar{v} + \Delta$ in the first round of trade whenever:

$$\begin{aligned} \bar{v} + \left(1 - \frac{\pi_1}{2}\right)\Delta + \frac{\pi_1}{2}\rho W^*(\pi_2) \quad &\geq \quad \bar{v} + \frac{\pi_1}{2}(\Delta + \sigma_b) + \left(1 - \frac{\pi_1}{2}\right)\rho W^*(\pi_2) \\ \Leftrightarrow \frac{\Delta}{\sigma_b} \quad &\geq \quad \frac{\rho W^*(\pi_2)}{\sigma_b} + \frac{1}{2}\left(\frac{\pi_1}{1-\pi_1}\right), \end{aligned} \tag{30}$$

otherwise he quotes the high price $p = \bar{v} + \Delta + \sigma_b$. Since $W^*(\pi_2) > 0$, we know that this inequality is strictly more restrictive than condition (29) as long as $\pi_1 \geq \pi_2$, implying that if the seller quotes $p = \bar{v} + \Delta$ to the first buyer, he will quote $p = \bar{v} + \rho\Delta$ to the second buyer when needed.

As in a centralized market, we can rule out equilibria where the seller always quotes the high price to a buyer. Otherwise, the buyer would not acquire information and the seller would find it optimal to quote the low price instead. As a result, we can also rule out equilibrium where the buyer chooses $\pi_i = 1$, since it implies that the seller would find it optimal to quote the high price to that buyer and the same contradiction would arise.

In a conjectured equilibrium where the seller quotes the low price $p = \bar{v} + \Delta$ to the first buyer and the low price $p = \bar{v} + \rho\Delta$ to the second buyer, the first buyer picks π_1 to maximize:

$$\frac{\pi_1}{2}\sigma_b - \frac{c}{2}\pi_1^2, \tag{31}$$

meaning that in an interior optimum where $\pi_1^* \in (0, 1)$ we obtain:

$$\pi_1^* = \frac{\sigma_b}{2c}. \tag{32}$$

Further, the second buyer picks π_2 to maximize:

$$\frac{\pi_1^*}{2}\frac{\pi_2}{2}\rho\sigma_b - \frac{c}{2}\pi_2^2, \tag{33}$$

meaning that in an interior optimum where $\pi_2^* \in (0, 1)$ we obtain:

$$\begin{aligned} \pi_2^\star &= \frac{\pi_1^* \rho \sigma_b}{4c} \\ &= \frac{\rho}{2}\pi_1^{*2}. \end{aligned} \tag{34}$$

Note that, for any interior optimum $\pi_1^* \in (0, 1)$, it follows that $0 \leq \pi_2^* < \pi_1^*$. Finally, for the seller to indeed prefer to quote the low price in both rounds, we need:

$$\begin{aligned} \frac{\Delta}{\sigma_b} &\geq \frac{\rho W^*(\pi_2^*)}{\sigma_b} + \frac{1}{2}\left(\frac{\pi_1^*}{1-\pi_1^*}\right) \\ &= \left(1 - \frac{\pi_2^*}{2}\right)\rho\frac{\Delta}{\sigma_b} + \frac{1}{2}\left(\frac{\pi_1^*}{1-\pi_1^*}\right), \end{aligned} \tag{35}$$

which can be rewritten as:

$$\frac{\Delta}{\sigma_b} \geq \frac{1}{2}\left(\frac{1}{1-\rho+\frac{\rho\pi_2^*}{2}}\right)\left(\frac{\pi_1^*}{1-\pi_1^*}\right). \tag{36}$$

If that condition is satisfied, the social surplus from trade in equilibrium is:

$$\begin{aligned} &\pi_1^*\left(\frac{1}{2}(\Delta+\sigma_b) + \frac{1}{2}\left(\frac{\pi_2^*}{2}\rho(\Delta+\sigma_b) + (1-\pi_2^*)\rho\Delta\right)\right) + (1-\pi_1^*)\Delta \\ = &\left[1 - \frac{\pi_1^*}{2} + \frac{\rho\pi_1^*}{2}\left(1 - \frac{\pi_2^*}{2}\right)\right]\Delta + \frac{\pi_1^*}{2}\left(1 + \frac{\rho\pi_2^*}{2}\right)\sigma_b. \end{aligned} \tag{37}$$

4.3 Optimal Market Structure

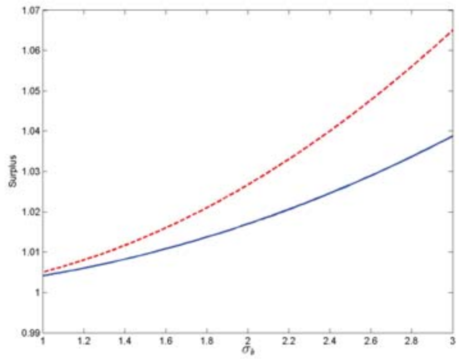
As earlier, we parameterize the model and compare the social efficiency of trade across the two venues. In contrast to the previous section however, buyers' information sets are now endogenous. We normalize $\Delta = 1$ and set $c = 15$. In Figures 2-3 we plot the social surplus from trade, net of information acquisition costs, and the privately optimal information acquisition as a function of the uncertainty in private valuations (σ_b), for various parameterizations of ρ.

The plots highlight that the trading venue that maximizes the social surplus from trade, net of information acquisition costs, varies with asset characteristics and the severity of trade delays in decentralized markets. Panel (a) in Figure 2 shows that, when trade delays are not too costly (e.g., $\rho = 0.8$), a decentralized market socially dominates a centralized market. Decentralized trade gives the first buyer greater assurance that information acquisition will be worthwhile — the first buyer obtains the asset with probability 1 when accepting the offered price and can thus realize the gains to trade whenever he knows that he values the asset at $v_i = \bar{v} + \Delta + \sigma_b$. In contrast, in the centralized market buyers are competing for the asset and may not obtain the asset every time they accept the seller's price quote. Even if a buyer knows that he values the asset at $v_i = \bar{v} + \Delta + \sigma_b$, he might still lose the asset to the other buyer. In the centralized venue, the threat of competition thus reduces each buyer's private incentives for information production, potentially leading to lower allocational efficiency and welfare.

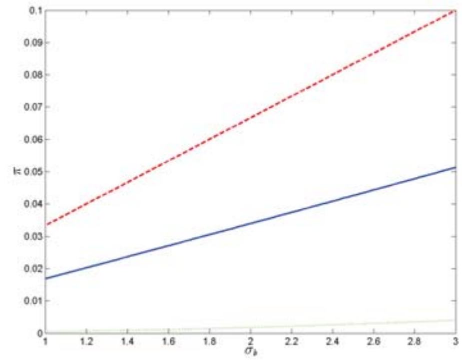
From a welfare perspective, decentralized trading can, however, also be inferior to centralized trading when the cost of trade delay is large. This result is evidenced by Panels (c) and (e) that compare the social surplus for the cases where $\rho = 0.5$ and $\rho = 0.2$. Yet, as shown in Figure 3, even in the case where $\rho = 0$, that is, all surplus is destroyed once the first buyer rejects a price quote, it is still possible for the decentralized market to be more efficient than a centralized market, provided that the uncertainty in private valuations σ_b is sufficiently large. When σ_b is large, the provision of sufficient incentives for information acquisition is essential and it is better achieved in a decentralized market.

5 Asymmetric Information about Common Value

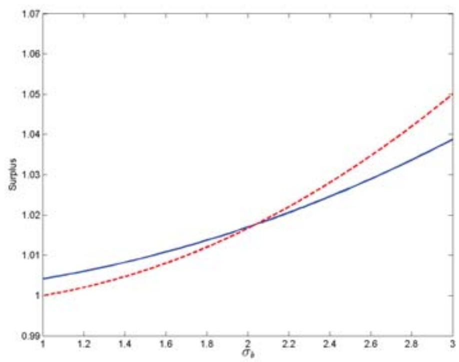
In this section, we extend our analysis to a case where equilibrium trading outcomes are driven by the surplus from trade (Δ) and the volatility of the asset's common value (σ_v). Hence, we set $\sigma_b = 0$ and assume that the uncertainty in common value is large enough to have $\sigma_v \geq \Delta$, meaning that the seller is better off keeping the asset than quoting a price $p = \bar{v} + \Delta - \sigma_v$.



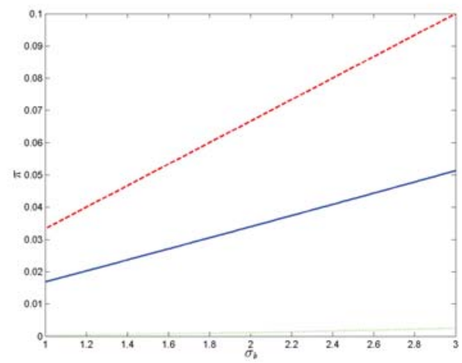
(a) Social surplus for $\rho = 0.8$.



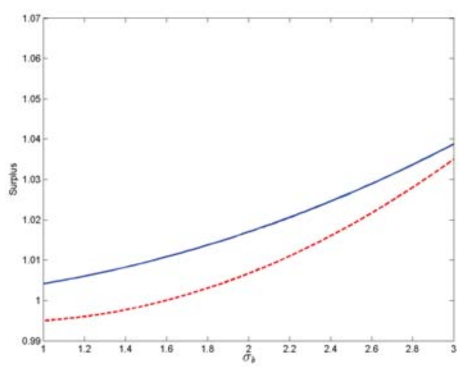
(b) Buyers' information for $\rho = 0.8$.



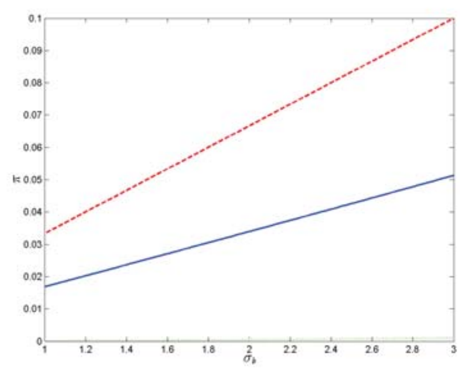
(c) Social surplus for $\rho = 0.5$.



(d) Buyers' information for $\rho = 0.5$.

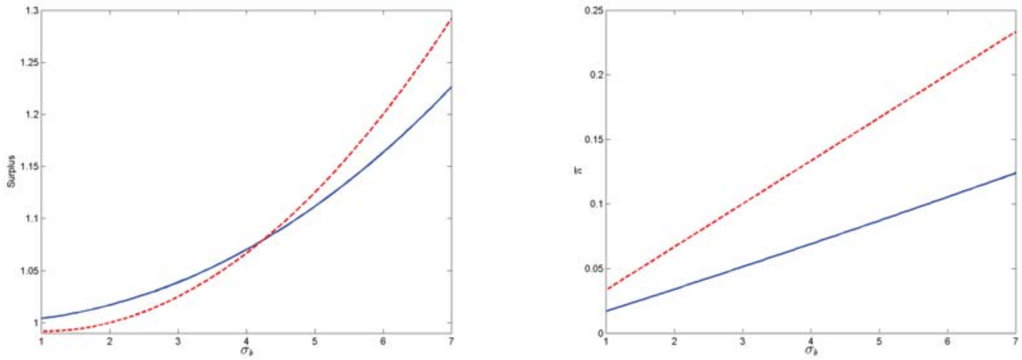


(e) Social surplus for $\rho = 0.2$.



(f) Buyers' information for $\rho = 0.2$.

Figure 2: **Surplus from trade and information acquisition with uncertain private values.** In these figures, we set $\Delta = 1$, $\sigma_v = 0$, and $c = 15$ and plot the social surplus from trade, net of the information costs, and the buyers' information as functions of the uncertainty in private valuations. In panels (a), (c), and (e), the dash line represents the surplus in the decentralized market while the solid line represents the surplus in the centralized market. In panels (b), (d), and (f), the dash line represents the first buyer's information π_1 and the dotted line represents the second buyer's information π_2 in the decentralized market, while the solid line represents the buyers' symmetric information in the centralized market.



(a) Social surplus for $\rho = 0$. (b) Buyers' information for $\rho = 0$.

Figure 3: **Surplus from trade and information acquisition with uncertain private values and $\rho = 0$.** In these figures, we set $\Delta = 1$, $\sigma_v = 0$, and $c = 15$ and plot the social surplus from trade, net of the information costs, and the buyers' information as functions of the uncertainty in private valuations. In panel (a), the dash line represents the surplus in the decentralized market while the solid line represents the surplus in the centralized market. In panel (b), the dash line represents the first buyer's information π_1 and the dotted line represents the second buyer's information π_2 in the decentralized market, while the solid line represents the buyers' symmetric information in the centralized market.

5.1 Centralized Market

The highest price the seller can post that has a positive probability of being accepted is $p = \bar{v} + \Delta + \sigma_v$. In the centralized market, this price is accepted only if at least one of the two buyers is informed and the asset is worth $v_i = \bar{v} + \Delta + \sigma_v$. This occurs with probability $\frac{1}{2}[\pi^2 + 2\pi(1-\pi)] = \pi\left(1 - \frac{\pi}{2}\right)$. By quoting this price, the seller collects an expected payoff of:

$$\pi\left(1 - \frac{\pi}{2}\right)(\bar{v} + \Delta + \sigma_v) + \pi\left(1 - \frac{\pi}{2}\right)(\bar{v} - \sigma_v) + \left[1 - 2\pi\left(1 - \frac{\pi}{2}\right)\right]\bar{v} = \bar{v} + \pi\left(1 - \frac{\pi}{2}\right)\Delta. \tag{38}$$

The seller may also consider quoting a price that is low enough to be accepted by buyers who do not have not private information, yet is higher than the value of keeping the asset. An informed buyer accepts a price $p > \bar{v}$ only when his $v_i = \bar{v} + \Delta + \sigma_v$. Since informed buyers now condition their trading decision on a common value component, an uninformed buyer needs to protect himself against the private information of competing buyers. There is thus adverse selection among buyers as any uninformed buyer recognizes that he is sure to get the asset if the other buyer is informed and $v = \bar{v} - \sigma_v$, but he only gets the asset with probability $1/2$ if the other buyer is informed and $v = \bar{v} + \sigma_v$. The highest price an uninformed buyer is willing to pay for the asset is then:

$$\frac{\frac{\pi}{2}(\bar{v}-\sigma_v)+\frac{\pi}{2}(\bar{v}+\sigma_v)\frac{1}{2}+(1-\pi)\bar{v}\frac{1}{2}}{\frac{\pi}{2}+\frac{\pi}{2}\frac{1}{2}+(1-\pi)\frac{1}{2}}+\Delta=\bar{v}-\left(\frac{\pi}{2+\pi}\right)\sigma_v+\Delta. \tag{39}$$

This price is rejected only if both buyers are informed and $v = \bar{v} - \sigma_v$. By quoting a price $p = \bar{v} - \left(\frac{\pi}{2+\pi}\right)\sigma_v + \Delta$, the seller collects an expected payoff of:

$$\left(1-\frac{\pi^2}{2}\right)\left[\bar{v}-\left(\frac{\pi}{2+\pi}\right)\sigma_v+\Delta\right]+\frac{\pi^2}{2}(\bar{v}-\sigma_v)=\bar{v}+\left(1-\frac{\pi^2}{2}\right)\Delta-\pi\left(\frac{1+\pi}{2+\pi}\right)\sigma_v. \tag{40}$$

Finally, the seller may consider quoting a price $p = \bar{v} + \Delta - \sigma_v$, which is accepted by all buyers, but quoting this price is dominated by keeping the asset which in expectation is worth $\bar{v}$ to him. Keeping the asset is, however, dominated by quoting the high price $p = \bar{v} + \Delta + \sigma_v$.

The seller thus quotes the price $p = \bar{v} - \left(\frac{\pi}{2+\pi}\right)\sigma_v + \Delta$ whenever:

$$\begin{aligned}\bar{v}+\left(1-\frac{\pi^2}{2}\right)\Delta-\pi\left(\frac{1+\pi}{2+\pi}\right)\sigma_v &\geq \bar{v}+\pi\left(1-\frac{\pi}{2}\right)\Delta\\ \Leftrightarrow \frac{\Delta}{\sigma_v} &\geq \left(\frac{1+\pi}{2+\pi}\right)\left(\frac{\pi}{1-\pi}\right),\end{aligned} \tag{41}$$

and in such case, the social surplus from trade is $\left(1-\frac{\pi^2}{2}\right)\Delta$. Otherwise, the seller quotes the high price $p = \bar{v}+\Delta+\sigma_v$ and the social surplus from trade is $\pi\left(1-\frac{\pi}{2}\right)\Delta$. From a social standpoint, the surplus from trade is greater if the seller quotes the low price $p = \bar{v} - \left(\frac{\pi}{2+\pi}\right)\sigma_v + \Delta$ than the high price $p = \bar{v}+\Delta+\sigma_v$ whenever:

$$\begin{aligned}\left(1-\frac{\pi^2}{2}\right)\Delta &\geq \pi\left(1-\frac{\pi}{2}\right)\Delta\\ \Leftrightarrow \pi &\leq 1\end{aligned} \tag{42}$$

Hence, in the region where $\frac{\Delta}{\sigma_v} < \left(\frac{1+\pi}{2+\pi}\right)\left(\frac{\pi}{1-\pi}\right)$, the seller quotes a socially inefficient, high price.

5.2 Decentralized Market

We now analyze how trade occurs in the decentralized market. Since $\sigma_v > 0$, a rejection in the first round of trade can be informative about the common value of the asset and will affect the behaviors of the seller and any uninformed buyer. To keep the analysis simple and shut down the signalling game between the seller and an uninformed second buyer, we solve for equilibria where the second buyer's beliefs about how trade occurred in the first round is unaffected by a price deviation by the seller in the second round. In other words, the second buyer's off-equilibrium beliefs about the value of the asset are the same as his equilibrium beliefs.

First, we conjecture an equilibrium in which the seller quotes a low price $p = \bar{v} + \Delta$ to the first buyer. This price is only rejected by an informed buyer who knows that $v = \bar{v} - \sigma_v$. Hence, both the seller and the second buyer know that the asset is then worth $v_i = \bar{v} + \rho\Delta - \sigma_v$ to the second buyer and $v = \bar{v} - \sigma_v$ to the seller. The seller quotes a price $p = \bar{v} + \rho\Delta - \sigma_v$ to the second buyer, which is accepted with probability 1. For this outcome to be an equilibrium, we need to verify that the seller finds it optimal to quote a price $p = \bar{v} + \Delta$ rather than $p = \bar{v} + \Delta - \sigma_v$ to the first buyer. Note that if he were to deviate to quoting the high price to the first buyer, the seller could be tempted to retain the asset in the second round. The seller, however, still finds it optimal to quote the second buyer a low price $p = \bar{v} + \rho\Delta - \sigma_v$ in the second round despite a deviation in the first round whenever:

$$\begin{aligned} \bar{v} + \rho\Delta - \sigma_v &\geq \frac{\frac{\pi}{2}(\bar{v} - \sigma_v) + (1-\pi)\bar{v}}{\frac{\pi}{2} + (1-\pi)} = \bar{v} - \frac{\pi}{2-\pi}\sigma_v \\ \Leftrightarrow \frac{\Delta}{\sigma_v} &\geq \frac{2}{\rho}\left(\frac{1-\pi}{2-\pi}\right). \end{aligned} \tag{43}$$

If this condition is satisfied, then the seller finds it optimal to quote a price $p = \bar{v} + \Delta$ to the first buyer whenever:

$$\begin{aligned} \left(1 - \frac{\pi}{2}\right)(\bar{v} + \Delta) + \frac{\pi}{2}(\bar{v} + \rho\Delta - \sigma_v) &\geq \frac{\pi}{2}(\bar{v} + \Delta + \sigma_v) + \left(1 - \frac{\pi}{2}\right)(\bar{v} + \rho\Delta - \sigma_v) \\ \Leftrightarrow \frac{\Delta}{\sigma_v} &\geq \frac{3\pi - 2}{2(1-\pi)(1-\rho)}. \end{aligned} \tag{44}$$

If condition (43) is violated however, condition (44) which guarantees that the seller quotes a price $p = \bar{v} + \Delta$ to the first buyer is replaced by:

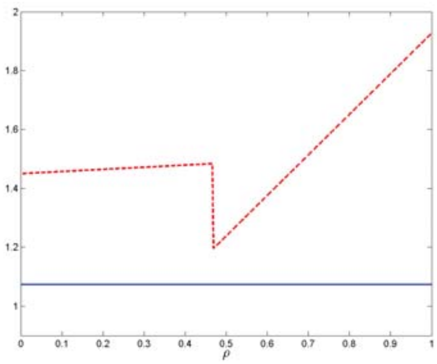
$$\begin{aligned} \left(1 - \frac{\pi}{2}\right)(\bar{v} + \Delta) + \frac{\pi}{2}(\bar{v} + \rho\Delta - \sigma_v) &\geq \frac{\pi}{2}(\bar{v} + \Delta + \sigma_v) + \left(1 - \frac{\pi}{2}\right)\left(\bar{v} - \frac{\pi}{2-\pi}\sigma_v\right) \\ \Leftrightarrow \frac{\Delta}{\sigma_v} &\geq \frac{\pi}{2\left(1 - \pi + \frac{\rho\pi}{2}\right)}. \end{aligned} \tag{45}$$

In such equilibrium, the social surplus from trade is $\left(1 - \frac{\pi}{2} + \frac{\rho\pi}{2}\right)\Delta$. When it exists, this equilibrium socially dominates any equilibrium where the seller quotes the first buyer a high price $p = \bar{v} + \Delta + \sigma_v$, since such an equilibrium can at most create a surplus of $\left[\frac{\pi}{2} + \left(1 - \frac{\pi}{2}\right)\rho\right]\Delta$. When the seller quotes the high price to the first buyer, trade occurs only with probability $\frac{\pi}{2}$ in the first round and, even if the second buyer accepts with probability 1 the price quoted by the seller, the surplus is strictly lower than the surplus in the equilibrium above due to the cost of delay when $\rho < 1$.

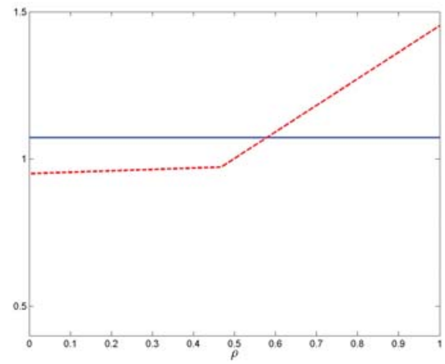
5.3 Optimal Market Structure

Now, we compare the social efficiency of trade across the different types of market. By inspecting condition (44), we see that it is satisfied for any values of ρ and σ_v as long as $\pi \leq \frac{2}{3}$. By inspecting condition (45), we see that it is satisfied for any values of ρ as long as $\frac{\Delta}{\sigma_v} \geq \frac{1}{2}\left(\frac{\pi}{1-\pi}\right)$. Since all our parameterizations in Figure 1 of Subsection 3.3 satisfy these conditions when we replace σ_v by σ_b, in Figure 4 we produce similar plots but for the case where the uncertainty is about the common value, i.e., $\sigma_v = 10$ but $\sigma_b = 0$, and compare them with those for the analog case where the uncertainty is about private values, i.e., $\sigma_b = 10$ but $\sigma_v = 0$.

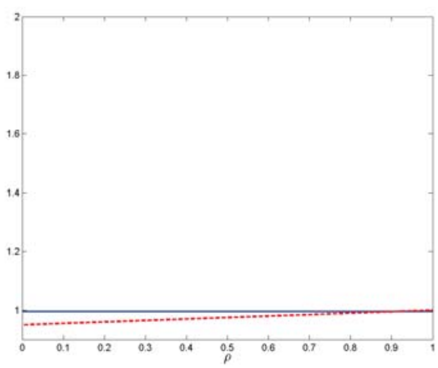
First note that in this specific parameterization, the seller finds it optimal to quote the high, less efficient price $p = \bar{v} + \Delta + \sigma_b$ in a centralized market with uncertainty in private valuations but he does not find it optimal to quote the high, less efficient price $p = \bar{v} + \Delta + \sigma_v$ in a centralized market with uncertainty in common value. This difference is due to the fact that the cutoff on $\frac{\Delta}{\sigma_v}$ in condition (41) is always lower than the cutoff on $\frac{\Delta}{\sigma_b}$ in condition (3) when $\pi \in (0, 1)$. Thus, for a given level of uncertainty, the seller's incentives to quote a high price are stronger when this uncertainty is in private values and allows for different valuations across buyers rather than when this uncertainty is in the common value. Hence, as we can observe from the parameterization of Figure 4, the difference in the social efficiency of trade between the two types of market is much larger quantitatively when the uncertainty is in private rather than in common values. In the former (see panel (a)), decentralizing trade is socially optimal for any value of ρ, whereas in the latter (see panel (c)), it is only the case for ρ close to 1. The reason why decentralizing trade is socially optimal for $\rho \to 1$ when $\sigma_v = 10$ and $\sigma_b = 0$ is that in equilibrium trade occurs with probability 1 in the second round of trade since both traders involved have learned from the refusal of the first buyer to pay $p = \bar{v} + \rho\Delta$ that $v = \bar{v} - \sigma_v$ and therefore, these traders are symmetrically informed. The seller thus never ends up with the asset in a decentralized market, which is not the case under centralized trade, where the seller must retain the asset whenever both buyers are informed and $v = \bar{v} - \sigma_v$. When ρ is close to 1, this higher probability



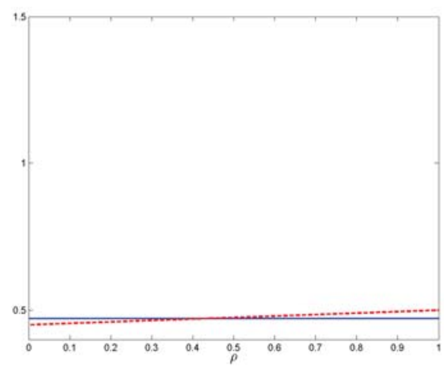
(a) Social surplus for $\sigma_b = 10$ and $\sigma_v = 0$.



(b) Seller's surplus for $\sigma_b = 10$ and $\sigma_v = 0$.

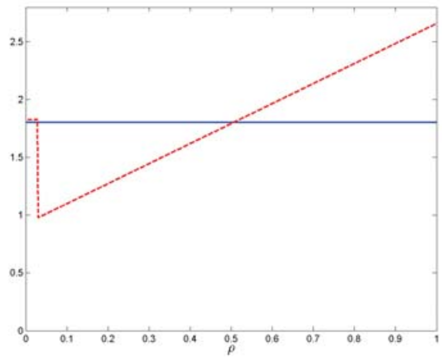


(c) Social surplus for $\sigma_b = 0$ and $\sigma_v = 10$.

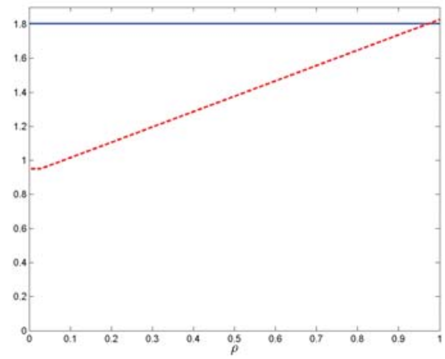


(d) Seller's surplus for $\sigma_b = 0$ and $\sigma_v = 10$.

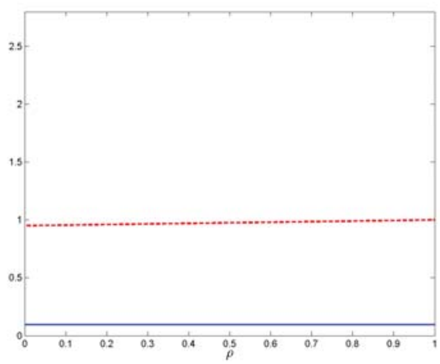
Figure 4: **Surplus from trade with low uncertainty in private vs. common values.** In these figures, we set $\Delta = 1$ and $\pi = 0.1$ and plot the social surplus from trade and the seller's expected surplus as functions of the discount factor when trade is delayed. The dash line represents the surplus in a decentralized market while the solid line represents the surplus in a centralized market.



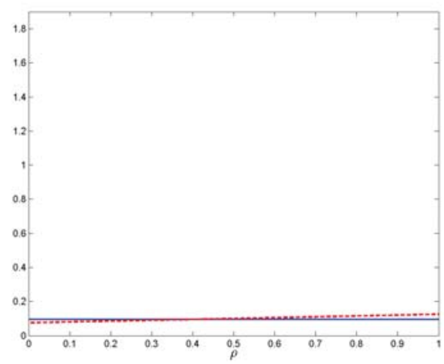
(a) Social surplus for $\sigma_b = 17.5$ and $\sigma_v = 0$.



(b) Seller's surplus for $\sigma_b = 17.5$ and $\sigma_v = 0$.



(c) Social surplus for $\sigma_b = 0$ and $\sigma_v = 17.5$.



(d) Seller's surplus for $\sigma_b = 0$ and $\sigma_v = 17.5$.

Figure 5: **Surplus from trade with high uncertainty in private vs. common values.** In these figures, we set $\Delta = 1$ and $\pi = 0.1$ and plot the social surplus from trade and the seller's expected surplus as functions of the discount factor when trade is delayed. The dash line represents the surplus in a decentralized market while the solid line represents the surplus in a centralized market.

of trade swamps the small cost of delay incurred by the sequential nature of trade and makes decentralized trade socially optimal.

In Figure 5, we increase the level of uncertainty until the seller finds it optimal to quote the high, less efficient price in a centralized market, regardless of whether this uncertainty is in private values or in the common value. In such case, decentralizing trade becomes socially optimal for any value of ρ when the uncertainty is in the common value, but this is not the case when the uncertainty is in private values. In panel (c), we can see that the surplus from trade in a decentralized market when the seller quotes $p = \bar{v} + \Delta$ to the first buyer and $p = \bar{v} + \rho\Delta - \sigma_v$ to the second buyer is very close to the full surplus $\Delta = 1$, whereas it is much lower in a centralized market where the seller finds it privately optimal to quote the high, less efficient price $p = \bar{v} + \Delta + \sigma_v$. Overall, these findings illustrate that whether the asymmetric information is over the private or the common values, decentralizing trade may incentivize asymmetrically informed agents to change their trading behaviors in ways that are socially beneficial.

6 Information Acquisition with Uncertain Common Value

In this section we extend our analysis to allow for information acquisition about the common value component. As earlier, buyer i incurs a cost $\frac{c}{2}\pi_i^2$ in order to learn v_i with probability π_i.

6.1 Centralized Market

In a first step, we repeat our analysis from the previous section, but allow for the probabilities π_i and π_j to be different from each other. The highest price the seller can post that has a positive probability of being accepted is $p = \bar{v} + \Delta + \sigma_v$. In the centralized market, this price is accepted only if at least one of the two buyers is informed and knows that $v = \bar{v} + \sigma_v$, which occurs with probability:

$$\frac{1}{2}\left[\pi_i + (1-\pi_i)\pi_j\right] = \frac{1}{2}\left(\pi_i + \pi_j - \pi_j\pi_i\right). \tag{46}$$

By quoting this price, the seller collects an expected payoff of:

$$(\pi_i + \pi_j - \pi_j\pi_i)\left[\frac{1}{2}(\bar{v} + \Delta + \sigma_v) + \frac{1}{2}(\bar{v} - \sigma_v)\right] + \left[1 - (\pi_i + \pi_j - \pi_j\pi_i)\right]\bar{v} = \bar{v} + \frac{1}{2}\left(\pi_i + \pi_j - \pi_j\pi_i\right)\Delta. \tag{47}$$

The seller may also consider quoting a price that is low enough to be accepted by buyers who do not have private information, yet is higher than the value of keeping the asset. The highest price an uninformed buyer i is willing to pay for the asset, given his adverse selection concerns regarding buyer j's private information, is:

$$\frac{\frac{\pi_j}{2}(\bar{v} - \sigma_v) + \frac{\pi_j}{2}(\bar{v} + \sigma_v)\frac{1}{2} + (1-\pi_j)\bar{v}\frac{1}{2}}{\frac{\pi_j}{2} + \frac{\pi_j}{2}\frac{1}{2} + (1-\pi_j)\frac{1}{2}} + \Delta = \bar{v} - \left(\frac{\pi_j}{2+\pi_j}\right)\sigma_v + \Delta. \tag{48}$$

If $\pi_i \geq \pi_j$, a price $p = \bar{v} - \left(\frac{\pi_i}{2+\pi_i}\right)\sigma_v + \Delta$ is rejected only if both buyers are informed and $v = \bar{v} - \sigma_v$. For the centralized market we focus on symmetric equilibria where $\pi_i = \pi_j = \pi$. By quoting $p = \bar{v} - \left(\frac{\pi}{2+\pi}\right)\sigma_v + \Delta$ the seller collects an expected payoff of $\bar{v} + \left(1 - \frac{\pi^2}{2}\right)\Delta - \pi\left(\frac{1+\pi}{2+\pi}\right)\sigma_v$, as derived in equation (40).

As shown in the previous section, the seller quotes the low price $p = \bar{v} - \left(\frac{\pi_1}{2+\pi_1}\right)\sigma_v + \Delta$ whenever:

$$\frac{\Delta}{\sigma_v} \geq \left(\frac{1+\pi}{2+\pi}\right)\left(\frac{\pi}{1-\pi}\right), \tag{49}$$

and in this case, the social surplus from trade is $\left(1 - \frac{\pi^2}{2}\right)\Delta$.

As with uncertain private valuations, we can rule out equilibria where π_i and π_j are high enough for the seller to always quote the high price. In such case, buyers would be better off not acquiring information and the high price would be rejected. Thus, in the following, we conjecture a symmetric equilibria where, with probability 1, the seller quotes a price that is accepted by uninformed buyers.

If buyer j acquires information with probability π and believes that buyer i will do the same, buyer i optimally responds to these beliefs and actions by picking π_i that maximizes:

$$\begin{aligned} & \pi_i \frac{1}{2}\frac{1}{2}\left(\bar{v} + \sigma_v + \Delta - \left(\bar{v} - \left(\frac{\pi}{2+\pi}\right)\sigma_v + \Delta\right)\right) - \frac{c}{2}\pi_i^2 \\ = \; & \frac{\pi_i}{2}\sigma_v\left(\frac{1+\pi}{2+\pi}\right) - \frac{c}{2}\pi_i^2. \end{aligned} \tag{50}$$

Given an interior solution $\pi_i \in (0, 1)$ we obtain:

$$\pi_i = \frac{\sigma_v}{2c}\left(\frac{1+\pi}{2+\pi}\right). \tag{51}$$

Further, in a symmetric equilibrium, we have $\pi_i = \pi_j = \pi$, which yields:

$$\pi = \frac{\sigma_v}{2c}\left(\frac{1+\pi}{2+\pi}\right). \tag{52}$$

This equation has the following two roots:

$$-1 + \frac{\sigma_v \pm \sqrt{16c^2 + \sigma_v^2}}{4c}, \tag{53}$$

but since $\pi \in [0, 1]$, only the positive root can be a solution, that is,

$$\pi^* = -1 + \frac{\sigma_v + \sqrt{16c^2 + \sigma_v^2}}{4c}. \tag{54}$$

This is an equilibrium as long as $\pi^* \in (0,1)$ and the seller finds it optimal to quote the low price, that is:

$$\frac{\Delta}{\sigma_v} \geq \left(\frac{1+\pi^*}{2+\pi^*}\right)\left(\frac{\pi^*}{1-\pi^*}\right). \tag{55}$$

6.2 Decentralized Market

Again, we can rule out equilibria where the seller quotes either the high price $p = \bar{v} + \Delta + \sigma_v$ to the first buyer or the high price $p = \bar{v} + \rho\Delta + \sigma_v$ to the second buyer with probability 1. Hence, we conjecture an equilibrium in which the seller always quotes a low price $p = \bar{v} + \Delta$ to the first buyer ($i = 1$). This price is only rejected by an informed buyer who knows that $v = \bar{v} - \sigma_v$. In such case, both the seller and the second buyer ($i = 2$) conclude from the first buyer's rejection that the asset is worth $v_i = \bar{v} + \rho\Delta - \sigma_v$ to the second buyer and $v = \bar{v} - \sigma_v$ to the seller. The seller thus quotes a price $p = \bar{v} + \rho\Delta - \sigma_v$ to the second buyer, which is accepted with probability 1.

For this outcome to be an equilibrium, we need to verify that the seller finds it optimal to quote a price $p = \bar{v} + \Delta$ rather than $p = \bar{v} + \Delta - \sigma_v$ to the first buyer. Note that if he were to deviate to quoting the high price to the first buyer, the seller could be tempted to retain the asset in the second round. The seller, however, still finds it optimal to quote the second buyer a low price $p = \bar{v} + \rho\Delta - \sigma_v$ in the second round despite a deviation in the first round whenever:

$$\begin{aligned} \bar{v} + \rho\Delta - \sigma_v &\geq \frac{\frac{\pi_1}{2}(\bar{v} - \sigma_v) + (1-\pi_1)\bar{v}}{\frac{\pi_1}{2} + (1-\pi_1)} = \bar{v} - \frac{\pi_1}{2-\pi_1}\sigma_v \\ \Leftrightarrow \frac{\Delta}{\sigma_v} &\geq \frac{2}{\rho}\left(\frac{1-\pi_1}{2-\pi_1}\right). \end{aligned} \tag{56}$$

If this condition is satisfied, then the seller finds it optimal to quote a price $p = \bar{v} + \Delta$ to the first buyer whenever:

$$\begin{aligned} \left(1 - \frac{\pi_1}{2}\right)(\bar{v} + \Delta) + \frac{\pi_1}{2}(\bar{v} + \rho\Delta - \sigma_v) &\geq \frac{\pi_1}{2}(\bar{v} + \Delta + \sigma_v) + \left(1 - \frac{\pi_1}{2}\right)(\bar{v} + \rho\Delta - \sigma_v) \\ \Leftrightarrow \frac{\Delta}{\sigma_v} &\geq \frac{3\pi_1 - 2}{2(1-\pi_1)(1-\rho)}. \end{aligned} \tag{57}$$

If condition (56) is violated however, condition (57) that ensures that the seller finds it optimal to quote a price $p = \bar{v} + \Delta$ to the first buyer is replaced by:

$$\begin{aligned} \left(1 - \frac{\pi_1}{2}\right)(\bar{v} + \Delta) + \frac{\pi_1}{2}(\bar{v} + \rho\Delta - \sigma_v) &\geq \frac{\pi_1}{2}(\bar{v} + \Delta + \sigma_v) + \left(1 - \frac{\pi_1}{2}\right)\left(\bar{v} - \frac{\pi_1}{2 - \pi_1}\sigma_v\right) \\ \Leftrightarrow \frac{\Delta}{\sigma_v} &\geq \frac{\pi_1}{2\left(1 - \pi_1 + \frac{\rho\pi_1}{2}\right)}. \end{aligned} \quad (58)$$

In this equilibrium, the social surplus from trade is $\left(1 - \frac{\pi_1}{2} + \frac{\rho\pi_1}{2}\right)\Delta$.

In the conjectured equilibrium, the second buyer is reached only after the first buyer has private information stating that $v = \bar{v} - \sigma_v$. Since being contacted by the seller reveals this information to the second buyer, acquiring information is useless and $\pi_2^* = 0$.

When quoted a price $p = \bar{v} + \Delta$ by the seller, the first buyer picks π_1 to maximize his expected profit of:

$$\frac{\pi_1}{2}\left[\bar{v} + \sigma_v + \Delta - (\bar{v} + \Delta)\right] - \frac{c}{2}\pi_1^2 = \frac{\pi_1}{2}\sigma_v - \frac{c}{2}\pi_1^2. \quad (59)$$

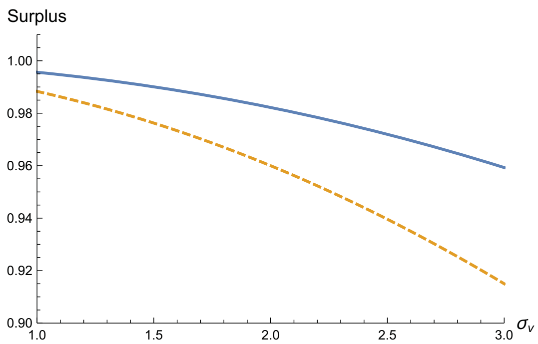
In an interior solution $\pi_1 \in (0, 1)$ we have:

$$\pi_1^\star = \frac{\sigma_v}{2c}. \quad (60)$$

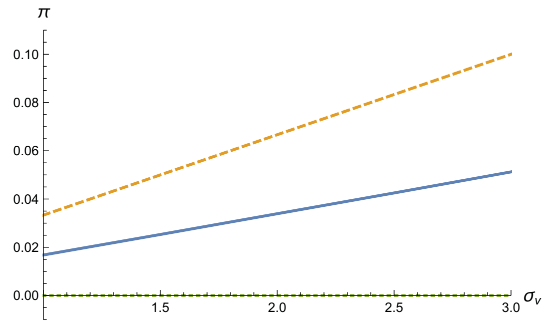
The two buyers' information strategies $\pi_1^* = \frac{\sigma_v}{2c}$ and $\pi_2^* = 0$ sustain an equilibrium whenever $\pi_1^* \in (0, 1)$ and the conditions for the equilibrium, as characterized by the inequalities (56)-(58), are satisfied. Note that all the conditions for the conjectured equilibrium are satisfied for high enough values of the cost parameter c.

6.3 Optimal Market Structure

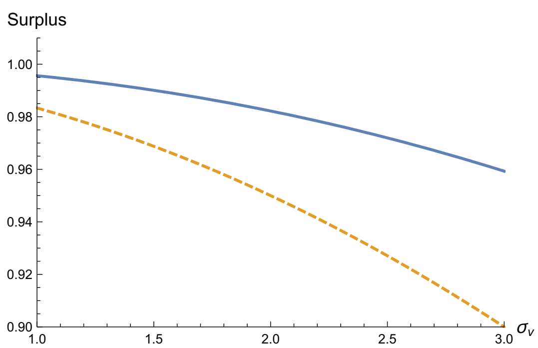
Figure 6 compares the social surplus and the buyers' information acquisition in the two types of market as a function of σ_v. In all our parameterizations, centralizing trade is socially optimal. A key reason for this result is the fact that, in the presence of common value uncertainty, information generates an adverse selection problem that reduces the efficiency of trade, but unlike with private value uncertainty, this information is not required to better allocate the asset to its efficient holder. Thus, the trading venue that provides lower incentives for information acquisition becomes the socially optimal one. Since competition between buyers in the centralized market lowers their ex ante incentives for information acquisition in comparison to the



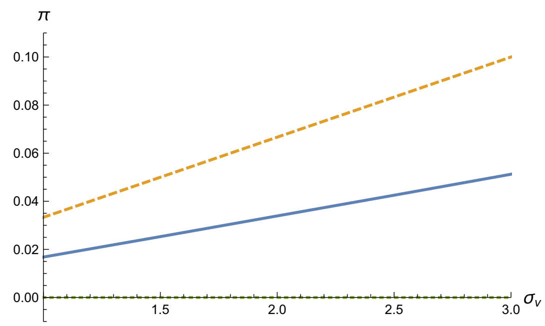
(a) Social surplus for $\rho = 0.8$.



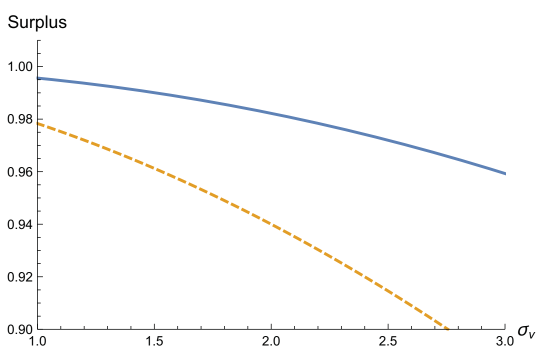
(b) Buyers' information for $\rho = 0.8$.



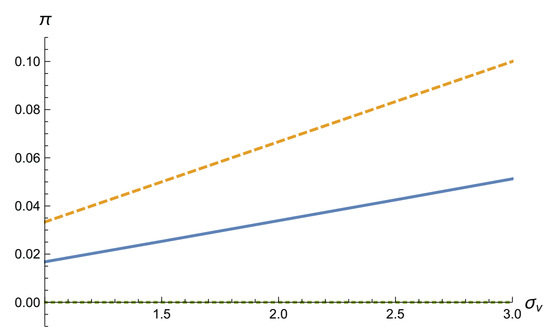
(c) Social surplus for $\rho = 0.5$.



(d) Buyers' information for $\rho = 0.5$.



(e) Social surplus for $\rho = 0.2$.



(f) Buyers' information for $\rho = 0.2$.

Figure 6: **Surplus from trade and information acquisition with uncertain common value.** In these figures, we set $\Delta = 1$, $\sigma_b = 0$, and $c = 15$ and plot the social surplus from trade, net of the information costs, and the buyers' information as functions of the uncertainty in private valuations. In panels (a), (c), and (e), the dash line represents the surplus in the decentralized market while the solid line represents the surplus in the centralized market. In panels (b), (d), and (f), the dash line represents the first buyer's information π_1 and the dotted line represents the second buyer's information π_2 in the decentralized market, while the solid line represents the buyers' symmetric information in the centralized market.

decentralized market, a centralized market sustains a larger surplus from trade. Moreover, as we increase σ_v, buyers face higher private incentives to acquire (socially costly) information and the gap between the social efficiency of centralized and decentralized markets widens.

When compared to Figure 2, these plots clearly highlight that asymmetric information about the common value has very different implications than asymmetric information about private values. Since centralized trade typically weakens traders' incentives to acquire information, decentralized markets tend to socially dominate centralized markets when information is socially valuable (see Figure 2). Figure 5, however, shows that when information has no social value, despite the fact it provides an advantage to its acquirer in a rent-seeking game, centralizing trade can be used to lower the socially wasteful acquisition of information and improve the social efficiency of trade.

7 Conclusion

We study a model with asymmetrically informed traders and compare the social efficiency of trade between a centralized market and a decentralized market. Since decentralized trade often involves costly delays, centralizing trade is socially optimal in parameter regions where buyers' decision to acquire information and the seller's decision of which price to quote are not affected by the market structure. We uncover, however, three channels through which decentralizing trade incentivizes traders to change their behaviors in ways that are socially beneficial, whether traders' information sets are independent of the market structure or endogenous to it.

First, since centralized trade makes it more likely that a high price quote will be accepted quickly by at least one buyer, there exist situations where a seller would choose an aggressive, socially inefficient trading strategy in a centralized market, but would prefer a more conservative, socially efficient trading strategy in a decentralized market. Second, by being able to quote different prices to different buyers in a decentralized market, the seller may then price discriminate buyers based on their information and increase the probability that the asset ends up in the hands of its most efficient holder. Third, since centralized trade typically weakens traders' incentives to acquire information, decentralized markets tend to socially dominate centralized markets when private information is socially valuable and relates to traders' private valuations of the asset. The opposite is, however, true when private information relates to the common value of the assetn, hence only benefits a trader's rent-seeking ability in a zero-sum trading game. These conclusions strike us as important for understanding why municipal bonds and exotic derivatives are mostly traded in decentralized markets whereas stocks and standardized derivatives such as corporate call options are mostly traded in centralized markets.

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