Centralized vs decentralized markets in the laboratory: The role of connectivity

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Centralized vs Decentralized Markets in the Laboratory: The Role of Connectivity

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Abstract

This paper compares the performance of centralized and decentralized markets experimentally. We constrain trading exchanges to happen on an exogenously predetermined network, representing the trading relationships in markets with differing levels of connectivity. Our experimental results show that, despite having lower trading volumes, decentralized markets are not necessarily less efficient. Although information can propagate quicker through highly connected markets, we show that higher connectivity also induces informed traders to trade faster and exploit further their information advantages before the information becomes fully incorporated into prices. This not only reduces market efficiency, but it also increases wealth inequality. We show that, in more connected markets, informed traders trade not only relatively quicker, but also more, in the right direction, despite not doing it at better prices.

Keywords: *Experiments, financial markets, diffusion of information, decentralized trading.*
JEL Classification: *C92, D82, G14.*

1 Introduction

In the classical paradigm of competitive markets, no individual trader has market power, all buyers can freely trade with all sellers, and all of their trades clear via a centralized market mechanism that matches demand and supply. In reality, though, many markets are decentralized and segregated, whereby not all traders are fully "connected" to each other. Segregation may for instance occur because of information or transaction costs, which limit the ability or willingness of some market participants to interact and trade with each other.

Examples of decentralized markets include the Over-the-Counter (OTC) markets where many financial assets (e.g., foreign exchange, interest-rate and other derivatives, municipal and corporate bonds, bank loans, private equity and real estate) and most durable goods are traded in. In an OTC market, investors trade directly with a limited set of other investors and negotiate terms privately, often facing incomplete information about the prices traded elsewhere in the market. Investors may also buy or sell from dealers, thus improving overall market connectivity. But, each customer typically approaches a subset of the dealers of the market. Dealers also trade with each other in order to balance inventory and meet liquidity needs, but each dealer may only interact with a subset of the dealers of the market.

Regulators have voiced increasingly serious concerns about (the size of) the OTC markets, and the potential risks they create to the overall financial system. Following the disruption of several OTC markets during the financial crisis of 2008 (e.g., credit derivatives, asset backed securities, and repo agreements), many commentators and policy makers blamed decentralized trading for the inability of traders to quickly identify the prices of assets, thereby exacerbating the severity of the crisis. As a response, the Group of Twenty (G-20) committed to a variety of far-reaching regulatory reforms to contain the "threat posed by OTC trading on the financial system," including a move to trading securities on centralized, fully connected exchanges where other financial assets like stocks are traded.

The main concern against decentralized markets is, indeed, their ability to aggregate privately dispersed information. In an informationally efficient market asset prices reflect all available information. Efficiency can be achieved because traders owning private information on the value of an asset (the 'insiders') seek to profit from mispricing, as long as prices do not fully embody their private information. If markets are efficient, insiders' private information is worthless in the long run. But insiders can realize higher gains than other traders in the short run. Uninformed traders can also infer (and benefit from) the existence of insider information by observing the trading activity. This can either accelerate the process of convergence towards efficiency, or drive it away, if uninformed traders are mistaken in their inferences, as the literature on informational cascades demonstrates (Bikhchandani et al., (1998), Topol (1991)).

This paper shows, experimentally, that indeed decentralized markets do not necessarily perform worse than centralized markets. We show that, despite having lower trading volumes, decentralized markets are not necessarily less efficient. Although information can propagate quicker through highly connected markets, higher connectivity also induces informed traders to trade faster and exploit further their information advantages before the information becomes fully incorporated into prices. This not only tends to reduce market efficiency, but it also increases wealth inequality. In more connected markets, informed traders trade not only relatively quicker, but also more, in the right direction, despite not doing it at better prices.

Subjects in our experiment can trade a financial asset with an uncertain payoff. Priorly, they receive private and, in some treatments, public signals about the true value of the asset. We constrain trading exchanges to happen on an exogenously predetermined network. Networks are a natural tool to represent the trading relationships in markets with decentralized trade and intermediation.[1] Traders can buy and sell an asset via 'personalized' a limit order book, in which they can see, and match, the bids and asks of the traders they are linked to in the trading network. This design feature, used in reality in some foreign exchange markets, allow us to change the connectivity of the market, spanning from fully connected centralized to bilateral/multilateral trading markets without changing the price formation mechanism.[2]

Our market-level results show that trading volume increases significantly when connectivity increases. But market efficiency does not significantly improve with connectivity. Conceptually,

[1] In decentralized markets, stable buyers-sellers trading relationships are usually formed. For example Kirman and Vriend (2001) show that loyalty networks exist between buyers and sellers in the Marseille fish market. In this respect, a decentralized market can essentially be represented as a graph in which the nodes correspond to traders and the edges represent potential (or realised) trading relationships between pairs. When the network is complete, every possible trading opportunity is present and therefore there is no constraint on trading patterns. On the other hand, the incompleteness of the network signifies that some traders are unable to trade with each other. This implies either the pure loss of trading opportunities or the fact that an intermediation service is required for trading.

[2] Several platforms in the foreign exchange spot market use a similar arrangement, or quasi-centralized limit order book structure, including Reuters, EBS, and Hotspot FX, which together facilitate a mean turnover in excess of 0.6 trillion US dollars (USD) each day (Gould et al., 2017).

connectivity has two opposing effects on market efficiency and wealth distribution. On the one hand, information can propagate quicker through highly connected markets, reducing market inefficiency and profit opportunities from information asymmetry (which is the standard argument against OTC markets). But, on the other hand, higher connectivity allows informed traders to trade faster with several counterparties and exploit their information advantages further, before information becomes fully incorporated into the price. This may not only increase wealth inequality but also reduce efficiency, as it is more likely to generate informational cascades. Our results show that the latter effect may be more important than the first, thus associating higher connectivity to more wealth inequality and not necessarily to more efficiency.

Thus, our market-level results suggest that informed traders, the "insiders," can better exploit their information advantages when markets are better connected. We subsequently investigates how insiders' strategies are affected by the degree of market decentralization. Informed traders in our setup have to balance two opposite effects when deciding on their trading strategies. On the one hand, they may opt to refraining from trading early due to the fear of being detected. On the other hand, they may feel compelled to make use of their information rather quickly, in fear that other insiders may take advantage of their information and exploit the uninformed ("outside") investors before they themselves can. Our experimental evidence shows that the latter effect may dominate the former. We show that insiders gain disproportionately more than outsiders in better connected networks by trading, not only quicker, but more, in the right direction, despite not doing it at better prices.

Our paper contributes to the literature that analyses the performance of decentralised markets by showing, experimentally, that limited connectivity may do more good than harm. Experimental methods are particularly suitable to test the performance of decentralized markets, as they can incorporate some of the inherent complexities of non-fully connected, segregated markets that have to be neglected in theoretical models. Field work is also unable to observe some of the crucial variables, such as the fundamental value of financial assets and the distribution of information among traders. The experimental approach allows us to exogenously control traders' preferences and trading partners, as well as their private information, while market efficiency and wealth inequality can be directly measured. Despite the relevance of decentralised markets, and the potential of experimental work, we know of very few experimental studies that have explored the efficiency properties of these markets and compared them to those of the centralized markets.

Our paper also contributes to the literature on insider trading by showing that superiorly informed traders are able to earn larger profits in centralized markets, and how. Insider trading remains an important concern of regulators because its effects have not been totally clarified. The primary argument against insider trading is that it works to the disadvantage of outsiders (who may ultimately exit the marketplace). The argument in favor of insider trading is that such trading leads to more informative security prices. We find evidence that the former may be more of a concern in centralized markets, without having the advantages of the latter. To our knowledge, ours is the first paper to compare the resulting levels of wealth inequality of centralised and decentralised markets.

2 Literature review

While the microstructure of markets is recognized as an important determinant of the degree of market efficiency, there is still limited academic work comparing how centralised and decentralised markets perform. Recent theoretical papers have started challenging the conventional wisdom that points to the informational inefficiencies of decentralized as compared to centralized markets. Malamud and Rostek (2017), for instance, argue that decentralized markets may allocate more risk to less risk-averse agents, thus providing higher total welfare. Glode and Opp (2017) argue that the delays associated with decentralized trading can incentivize traders to choose less aggressive, socially more efficient trading strategies.

Despite the potential of the experiments in this area, we know of very few experimental studies that have compared the efficiency properties of decentralized and centralized markets. Attanasi et al (2016) is, to our knowledge, the only existing study using (classroom) experiments to compare an OTC market, in which each agent looks for the best counterpart through bilateral negotiations, and a continuous double action (CDA) market mechanism. Rather than connectivity, they focus on counterparty search and quote opacity, also typical of decentralised markets, and from which we deliberately abstract from in our study to concentrate on the role of connectivity. In their setting, centralized markets outperform decentralized ones.

A recent paper related to ours is Halim et al (2019), which also embeds an exogenous network structure within the framework of a Arrow-Debreu security market. In contrast to ours, the network provides a mechanism to share the imperfect information purchased by the individuals. The paper shows that costly information sharing through social communication networks increases trading volume. The authors interpret this counter intuitive result as a consequence of risk sharing opportunities among risk adverse traders rather than because investors are irrational. With social communication, while prices are more precise, i.e. closer to the Bayesian posterior, they are less informative. This is because a lower number of signals is purchased as a result of the free riding incentive provided by the sharing mechanism. Net earnings and welfare are higher with information sharing and, in contrast to our results, the extent of information aggregation increases with the density of the information network.[3]

These papers are part of a broader experimental literature on market efficiency. This literature has incorporated information asymmetries in two principal ways. The first is to provide some (but not all) of the traders in the market with perfect information. The alternative is to provide all traders with heterogeneous information. Early studies indicated that, when information is asymmetric but perfect, markets have a strong tendency to disseminate private information provided that enough individuals hold the information. These early studies suggest that efficiency increases with both the number of insiders and the experience of traders. A more recent literature, assuming more complex informational environments, has shown however, that information dispersed in the market is imperfectly incorporated into prices (Biais et al., 2005; Hanson et al., 2006; Veiga and Vorsatz, 2010; Corgnet et al., 2015, Lionel and Siemroth, 2018).[4]

Some papers, arguably more closely related to ours, investigate the deviations from full information efficiency of decentralized markets (Huber et al., 2011; Bossaerts et al., 2013; Asparouhova and Bossaerts 2017). Asparouhova and Bossaerts (2017) for instance use multiple

[3]In a theoretical paper Colla and Mele (2010) consider a model with strategic traders who are locally connected to common sources of information about the long term value of an asset. They also find that, compared to a market without network connections, a market with information linkages is characterized by higher volume, efficiency, and in general, higher liquidity.

[4]Rather than the role of connectivity, some papers focus on the pricing mechanism (e.g., Cason and Friedman, 1996, Morone and Nuzzo, 2015, Schnitzlein, 1996, and Theissen, 2000). Cason and Friedman (1996) compare, for instance, the performance of the continuous double auction (CDA), the uniform price double auction (UPDA), the single call market (SCM) and the multiple call market (MCM). The authors find that mean prices deviate the least from the Competitive Equilibrium (CE) prediction in the SCM, and the deviations for UPDA are no greater than the deviations in the MCM and CDA. This suggests that the increase in transaction opportunities afforded by the market arrangements causes prices to deviate more rather than less from the CE range.

private exchanges, as well as a single organised public exchange, to investigate the efficiency properties of “dark markets", in which order submissions are bilateral and transaction prices are known only to the trading counterparties. They find that prices in centralized markets remain closer to the fully revealing prices but dark markets do not fare that badly. **Rather than compare full transparency and full quote opacity, we focus on the intermediate effects of (the different degrees of) connectivity while retaining the same market mechanism across treatments.**

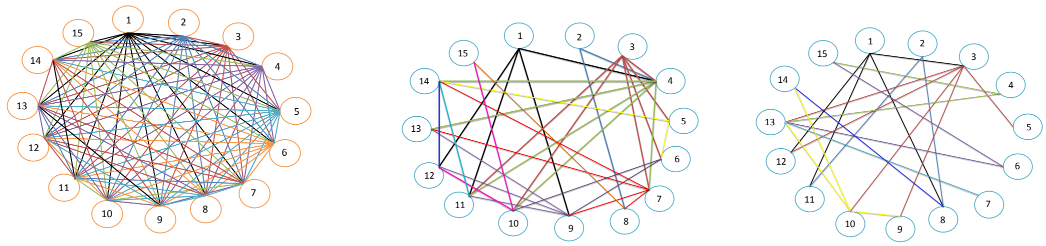
3 The Experimental Design

We run a series of independent experimental “markets” where we allow 15 subjects to continuously trade between each other for a period of 3 minutes. At the beginning of each market, each trader is endowed with 10 units of an asset as well as with 1000 units of experimental currency (ECU). Each unit of the asset pays a dividend D at the end of the market, where D is equal to 0 or 10 ECUs with equal probability.[5] The dividend payout is randomly determined at the beginning of the market, but it is not revealed to the traders until the end of the market. It is common knowledge that the two possible dividend values are equiprobable. Apart from the dividend payout, the asset is worthless.

We use a network framework to exogenously restrict the subjects' ability to trade between each other, which allows us to compare the performance of centralized and decentralized markets. Prior to the experiment, we created three different network structures of 15 nodes. In each of them, the edges between the nodes had a probability p of being activated, independent across edges. We used three different probabilities: $p = 1$ (a fully/highly connected market, "HC"), $p = 0.33$ (a medium connected market, "MC") and $p = 0.2$ (a low connected market, "LC").[6] Figure 1 illustrates the three realized networks (HC, MC, and LC). These three network structures give rise to three different treatments. The network structure in each treatment is fixed but each trader is randomly assigned to one of nodes of the network at the beginning

[5]The high level of cash ensures that traders are not cash-constrained. As shown later, trader profits will be defined in terms of the gains/losses relative to the initial level of cash.

[6]The probabilities of 0.33 and 0.2 are chosen so that the average degree is $5 = 15 * 0.33$ and $3 = 15 * 0.20$, respectively, one third and one fifth of the number of traders, 15. Both of these probabilities are above the “percolation” threshold, $p_c = 1/15 = 0.067$, which allows information to be diffused.



(a) HC (b) MC (c) LC

Figure 1: The networks used in the centralized/highly connected (HC), medium connected (MC) and low connected (LC) treatments. The numbers represent the nodes to which traders are randomly assigned in each market of each treatment.

of each market. All probabilities (but not the realizations) are known by the subjects.

Trading is organized as a networked continuous double auction market, allowing us to change the connectivity of the market without changing the price formation mechanism. Subjects can submit (and withdraw) "bids", i.e., (non-necessarily integer) prices at which they are willing to buy one unit of the asset, and "asks", i.e., (non-necessarily integer) prices at which they are willing to sell one unit of the asset, to a limit order book. At any point in time, offered quotes (bids and asks) can be accepted by the other traders. But the quotes of a trader will only be available to those traders she is connected to in the network. In other words, each subject can only observe and accept quotes of her "local" limit order book. Figure 2 below shows an example of a ("global") limit order book and the resulting local limit order book of subject 7, who is connected to subjects 3, 8, 13 and 14 but not 5, 6, 7, 9, 10 and 15.

Subjects receive noisy "signals" about the realized dividend value at the beginning of the market. Signals are presented to the subjects as taking values of 0 or 10. A signal of 0 (10) means that the realized dividend is 0 (10) with probability q and 10 (0) with probability $1-q$. In the main analysis, we set (and it is common knowledge that) $q = 0.8$. For $q = 0.8$ the expected (Bayesian) price is very close to the dividend.[7] In an extension, we compare the main

[7]The expected price, P, conditional on the total information available in the market, using Bayesian inference, would be:

$$P = 10 \cdot Pr(D = 10|I) + 0 \cdot Pr(D = 0|I) = 10\left[1 + \left(\frac{1-q}{q}\right)^{\eta}\right]^{-1}, \tag{1}$$

where N denotes the total number of subjects in the market, η the quantity of "net" private signals that suggest the dividend is 10 (number of private signals with value 10 minus number of private signals with value 0), I the information available in the market.

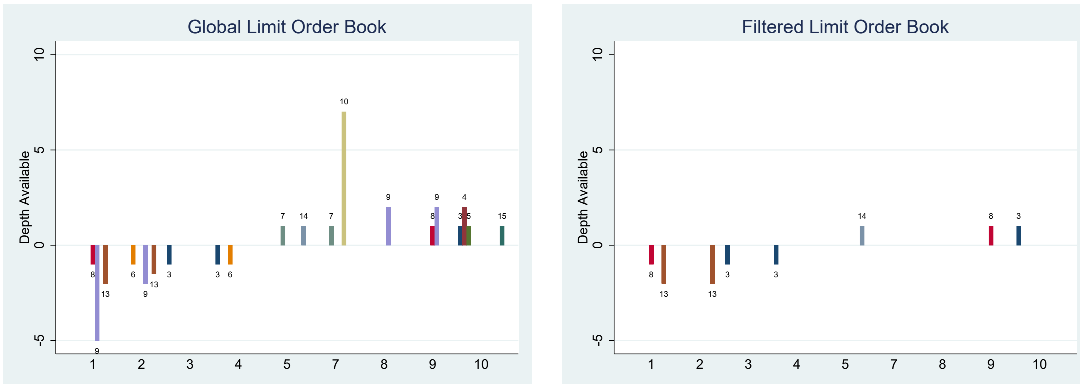


Figure 2: Negative levels of depth represent bids (willingness to buy) whereas positive levels represent asks (willingness to sell)

results with those obtained when lowering the precision of the private signal to $q = 0.66$.[8]

In all markets, each subject receives two private signals. As the realizations of the private signals across traders are different, their expected values of the fundamental are different and mutually agreable trades are possible. In some markets, subjects also receive a common public signal. Because of the importance of public signals, the trading environment is very different depending on whether the public signal is available, and if so, whether it is correct, i.e. equal to the true dividend. This makes us compare performance under three different trading environments: "No Public Info", "Correct Public Info" and "Incorrect Public Info." As compared to the case of no public information, a correct public signal narrows substantially the price range over which most of mutually agreeable trades are possible, whereas an incorrect public signal widens it substantially.[9]

[8] In that case, the expected (Bayesian) price is not identical to the dividend. Still, as we control for the quality of the net private information, we measure inefficiency relative to the dividend.

[9] Let us assume the correct dividend is $D = 10$. In the main analysis (with signal precision $q = 0.8$), the probability a given trader has two correct signals is 64%, one correct signal is 32% and two wrong signals is 4%. On average, out of 15 participants, the number of "informed" agents who receive two correct private signals is $N_2 = 9.6$, the number of agents who receive one correct signal is $N_1 = 4.8$ and the number of agents receiving two wrong signals is $N_0 = 0.6$. In case no public signal is released, the value of the fundamental expected by an agent endowed with x private signals suggesting that the true dividend is $D = 10$, f_0^x, is given by $f_0^2 = 9.41$ (using equation 1 with $\eta = 2$), agents who have one correct and one wrong signal will $f_0^1 = 5$ and $f_0^0 = 0.59$. Thus, in a fully connected market the (initial) number of pairs who can potentially mutually agree on the price (if agents were risk neutral) would then be $N_2 * N_1 + (N_2 + N_1) * N_0 = 46.1 + 8.6 = 54.7$.

In case a public signal is released, and assuming agents expectation of the fundamental is derived by equally weighting three signals, the expected value of the fundamental for an agent who has x signals suggesting that the dividend is $D = 10$ is $f_0^3 = 9.85$, $f_0^2 = 8$, and $f_0^1 = 0.66$ and $f_0^0 = 0.15$. While the number of potential trading partners is the same as in the case without public information, if the public signal is correct, the price range over

Subjects' net profits in each market consist of the dividend paid out and the gains or losses generated by the trading activity. Formally,

$$\Pi^i \equiv S_T^i D + (C_T^i - C_0^i), \tag{2}$$

where S_T^i is the number of stocks held by subject i at the end of the market and C_0^i and C_T^i are, respectively, her initial and final cash. Her final cash is determined by her initial cash, the price received for the units sold and the price paid for the units bought. Subjects can exchange as many assets as desired, as long as they have enough cash or assets (no short-sale is allowed).

Subjects' final payoffs are computed as the accumulated profits of the markets run in the session, and paid in cash at the end of the session.[10] In total, we run 6 treatments (highly, medium and low connectivity and with and without public information). Each treatment is run in a separate session with 15 subjects (each subject could only participate in one session). But each session consisted of a number of independent markets. As the public signal may be correct or incorrect, i.e. equal or different to the realized dividend, we doubled the number of sessions (and markets) of the treatments with public information for a total of 9 sessions.

The different treatments implemented as well as the per treatment number of markets, agents and signals, as well as the per-treatment average number of markets with the high dividend and with the correct public signal, are displayed in Table 1. We also include the per-market average number of net correct private signals, defined as the number of correct minus the number of incorrect private signals in the market.

which most of mutually agreeable trades are possible (that is between N_2 and N_1) is narrower at [8, 9.85] versus [5, 9.41]. As a result we expect to observe a decrease in trading volume when the public signal is correct. If the public signal is wrong, the price range over which most of mutually agreeable trades are possible is wider [0.66, 8] and as a result we would expect more trading volume when public information is wrong than when no public information is released.

When the information is correct 66% of the times (the low precision case), the probability a subject has two correct signals is 43.5%, one correct signal is 45%, and two wrong signals is 11.5%. On average, out of 15 participants, 6 have 2 correct signals, 7 have one correct and one wrong signals and 2 have two wrong signals. The expected values of the fundamentals in the low precision case are $f_0^2 = 7.90$, $f_0^1 = 5$, $f_0^0 = 2.10$. While the initial range over which trade can be agreed is narrower in this case, the number of pairs who initially can potentially trade (in a fully connected market) increases to (42 + 26= 68).

[10] One experimental currency unit is equivalent to 2 cents of €. The average payoff is about 20€ and each session lasted around 90 minutes. Note that subjects can make losses. To avoid some of the problems associated with subjects making real losses in experiments, we endow all subjects with a participation fee of 5€, which can be used to offset losses. No subject earned a negative final payoff in any session.

Table 1: Descriptive Statistics across Treatments

Treatments	Num of Markets	Num of Agents	Number of Signals	Dividend D=10	Public Signal Correct	Private Signals Net Private Info.
HC No Pub. Info.	10	15	30	0.30	-	18.4
MC No Pub. Info.	14	15	30	0.28	-	17.8
LC No Pub. Info.	15	15	30	0.46	-	18.8
HC Pub. Info.	30	15	31	0.60	0.80	18.7
MC Pub. Info.	30	15	31	0.46	0.73	19.2
LC Pub. Info.	30	15	31	0.46	0.77	18.6

4 Variables and Descriptive Statistics

Our variables, described in the following subsections, are defined at the market, subject and transaction levels. The summary descriptive statistics are described in Table 2.

4.1 Market Level

We define the following dependent variables at the market level: trading volume, inefficiency and inequality. Trading volume V_m in market m is defined as the total number of times the assets have been traded by any pair of agents in that market (each transaction involves one unit of the asset). As shown in Table 2, the trading volume differs depending on the availability and the quality of the public signal. As suggested earlier, the price range over which mutually agreeable trades are theoretically possible is narrower, and the actual trading volume is lower, when public information is released and it is correct than when it is not released. On the contrary, the price range over which mutually agreeable trades are possible is wider, and the trading volume is higher, when public information is released and it is wrong.

Market inefficiency $Inef_m$ in market m is defined as the average deviation of the price of each transaction from the fundamental (realized dividend), i.e.,

$$Inef_m = \frac{1}{V_m} \sum_{j=1}^{V_m} |P_{j,m} - D_m|, \tag{3}$$

where $P_{j,m}$ is the price of transaction j in market m and D_m the dividend in market m. As we can see in Table 2, inefficiency is greatest when the public signal exists and it is incorrect and lowest when the public signal exists but it is correct.

Table 2: Descriptive Statistics

	All Observations					No Public Info.	Correct Public Info.	Incorrect Public Info.
	Obs.	Mean	Median	Min.	Max.	Mean	Mean	Mean
Trading volumes	129	54.4	50	23	123	58.7	50.4	59.4
Inefficiency	129	2.19	1.81	0.07	8.14	2.95	1.07	4.46
Inequality	129	0.027	0.021	0.0008	0.132	0.040	0.013	0.052
Profit	1,935	46.51	28.3	-299.8	358.1	35.8	47.8	61.9
Stock Bought	1,935	3.62	1	0	83	3.92	3.35	3.96
Stock Sold	1,935	3.62	2	0	17	3.92	3.35	3.96
Stock Held	1,935	10	9	0	93	10	10	10
Price	7,017	4.95	5	0	10	4.19	5.05	6.05
Informed Agent	1,935	0.67	1	0	1	0.66	0.67	0.68
Connected Agent	1,935	0.46	0	0	1	0.50	0.44	0.47
Informed Buyer	7,017	0.65	1	0	1	0.57	0.68	0.74
Informed Seller	7,017	0.66	1	0	1	0.66	0.65	0.68
Connected Buyer	7,017	0.15	0	0	1	0.14	0.16	0.17
Connected Seller	7,017	0.18	0	1	1	0.19	0.18	0.20
Time	7,017	89.2	86	3	180	87.9	89.2	91.6

Market inequality is measured by the "Gini coefficient" of the individual profits of the 15 participants in the market, i.e.,

$$Ineq_m = \frac{\sum_i \sum_j \left|\Pi_m^i - \Pi_m^j\right|}{2 * 15 \sum_i \Pi_m^i},$$

where the profits Π_m^i of agent i market m are computed at the end of the market, taking into account the gains or losses generated by the trading activity and the dividend paid out at the end, as described in (**??**). The Gini coefficient is a measure of statistical dispersion. A Gini coefficient of zero expresses perfect equality, while a Gini coefficient of one expresses maximal inequality. However, a value greater than one may occur if the profits take negative values. We thus rescale profits by adding a common value across all markets and treatments, in order to make the lowest profit observation equal to zero. As in the case of inefficiency, inequality is greatest when the public signal exists and it is incorrect and lowest when the public signal exists but it is correct.

Our independent variables at the market level include dummies for connectivity: low and medium connectivity, as opposed to full connectivity, our base category. We also include dummies for having a correct public signal and an incorrect one, using the no public information as the default category. In terms of private signals, we use the number of net correct private signals, i.e. the number of correct minus the number of incorrect ones, as shown in Table 1.

4.2 Subject and Transaction Levels

We define the following dependent variables at the individual subject level: profits, stock bought, stock sold and stock held. Stock bought and sold counts the units of the asset bought and sold, respectively, by the agent during the market. Stock held counts the units of the asset held at the end of the market. Consistent with the trading volume results, the average number of stocks bought/sold described in Table 2 are lowest when public information is released and it is correct, and highest when public information is released and it is wrong. Average stock held at the end is of course equal to the initial endowement.

As independent variables, we use a dummy variable named "Informed agent", which takes a value of 1 if the subject has received two correct private signals, and a dummy variable named "Connected agent" which takes a value of 1 if the number of edges it has (the degree) is above the median in that market. As the probability of receiving a correct signal is 0.8, the fraction of informed traders is (approximately) 0.64.

At the transaction level, we can use the price of the transaction as a dependent variable. As independent variables, we can include characteristics of the two agents involved in the transaction, such as whether the buyer or the seller is “Informed” or “Connected.” We can also include the second in which that transaction occurs.

5 Experimental Results

We present the experiment results in three steps. We first show that (and provide an explanation for why) decentralized markets may not be more inefficient, despite involving less trade, with the advantage of generating less inequality between traders. We then dig deeper into the determinants of profits at the individual trader level. We show that informed traders perform better, especially in the presence of connectivity, because they manage to trade more in the right direction (although not at better prices). In the last subsection, we compare the main results to the case in which signals are less precise.

5.1 Market Performance of Decentralized Markets

This subsection compares the performance of decentralized versus centralized markets using market level data. We show both box plots and regression analysis results. The boxes plot the first and the third quartiles, and the band inside the boxes the second quartile (i.e., the median).[11] In the regression analysis, we first pool all the observations of all treatments and then we separate them by the availability and quality of the public information.

Lower trading volumes. The left panel of Figure 3 illustrates the box plots of the market trading volume by treatment. Intuitively, trading volume decreases when connectivity decreases, as the number of potential trading partners decreases. The reduction of trade volumes is especially important when moving from high connectivity (centralized market) to medium connectivity (decentralized but more connected than the low connectivity market). This is true independent of the availability and quality of the public information.[12]

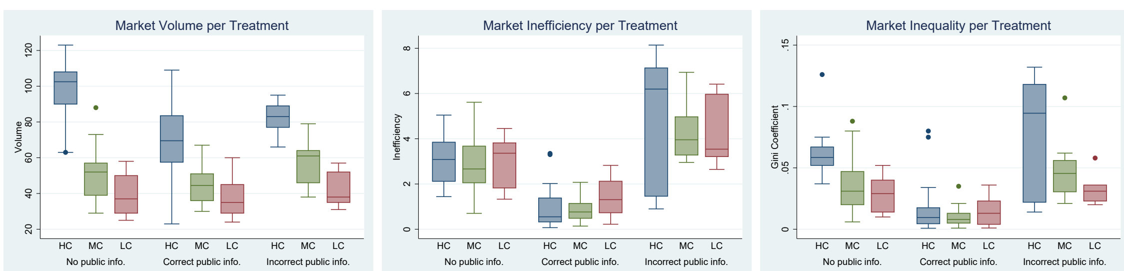


Figure 3: Market Trading Volume, Inefficiency and Inequality

These results are confirmed in the regressions shown in Table 3. The coefficients of the dummies for medium and low connectivity are negative and strongly significant in all the regressions, both in the pooled sample in column 1 as well as when separating out by the availability and the quality of the public information in columns 2-4. The coefficient for the low connectivity is more negative than the one for medium connectivity. Thus, in decentralized markets, trad-

[11]The whiskers extend *up to* 1.5 times the interquartile range from the top/bottom of the box to the furthest datum within that distance. If there are any data beyond that distance, they are represented individually as points ('outliers').

[12]A Mann-Whitney test (two sample t-test) rejects the null hypothesis of equal median (equal mean) at 1 % significance level between each pair of connectivity treatments (HC, MC and LC) within each of the three public signal environments (No Public Info, Correct Public Info and Incorrect Public Info).

Table 3: Market Trading Volume Estimations

	All	No Public Info.	Correct Public Info.	Incorrect Public Info.
Medium Connectivity	-30.419^{***}	-48.232^{***}	-24.506^{***}	-22.666^{**}
	(6.053)	(0.236)	(5.334)	(7.584)
Low Connectivity	-40.309^{***}	-58.389^{***}	-31.268^{***}	-37.625^{***}
	(5.425)	(0.174)	(3.490)	(4.909)
Correct Public Info.	-11.412^{*}			
	(5.290)			
Incorrect Public Info.	-0.520			
	(5.309)			
Net Private Info.	-0.491	-1.611^{*}	0.032	-0.405
	(0.282)	(0.434)	(0.371)	(0.947)
Constant	94.234^{***}	128.146^{***}	68.033^{***}	88.241^{***}
	(9.981)	(7.993)	(8.794)	(14.148)
Observations	129	39	69	21
R-squared	0.60	0.79	0.49	0.70

Trading volume is defined as the total number of times the assets have been traded by any pair of agents in that market. Low and medium connectivity are dummy variables where high connectivity is the base category. Correct and incorrect public information are dummy variables where no public information is the base category. The number of net correct private signals measures the difference between total number of correct and incorrect private information in a market. The standard errors corrected for market-level clustering, are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1, † p<0.15

ing volume is lower than in centralized markets, and as connectivity of decentralized markets decreases trading volumes decrease further.

Column 1 also shows that trading volume is lower when the public signal is correct, compared to the case of no public signal, as the probability of finding mutually agreeable prices is lower. If the public signal is incorrect, the trading volume is not significantly different than when it is not available. Interestingly, the quality of the private information is only relevant in the case in which the public is not available. As shown in the second column, the number of net correct private signals reduces trading volume when the public signal is not available.

Not more inefficient. The central panel of Figure 3 shows the box plots of market (in)efficiency. Not surprisingly, market inefficiency is greatest when the public signal is incorrect, and lowest when the public signal is correct. But, conditional on the availability and the quality of the public information, the level of inefficiency is similar across the three different levels of connectivity.[13]

[13] A Mann Whitney test (two sample t-test) fails to reject the null hypothesis of equal median (equal mean) at 1 % significance level between each pair of connectivity treatments (HC, MC and LC) within each of the three public signal environments (No Public Info, Correct Public Info and Incorrect Public Info).

All these results are confirmed in the pooled regressions in the first column of Table 4. The dummies of connectivity do not have significant effects in the overall regression. In the case of no public information, inefficiency in decentralized markets is even lower than in centralized markets, as shown by the negative and significant coefficients. Only in the case of correct public information and highly decentralized markets, decentralization leads to less efficiency than centralization.

In the first regression, the dummy of correct public information has a negative, significant effect on the level of market inefficiency whereas the dummy of incorrect public information has a positive, significant effect.[14] The regressions also show, both overall and in the split samples, that efficiency is greater if the quality of the private information increases. The coefficient for the net number of correct private signals is always negative and almost always significant. Comparing the magnitudes, the private signals are more important when there is no public signal and, especially, when there is but it is incorrect.

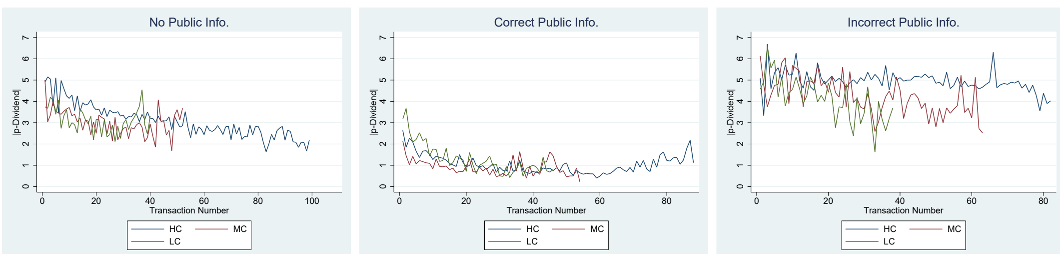


Figure 4: This figure displays, for each treatment, the average deviation of the price from the dividend as a function of the (number) order of the transaction in the market. Prices are averaged across all markets with the same level of connectivity (high, medium and low connectivity) and quantity and quality of information (no public, correct public, incorrect public).

We can understand the efficiency results further by depicting how prices evolve as the asset gets traded, i.e., as a function of the transaction number. Figure 4 shows that the price reached after a given number of transactions in the case of centralized markets is not closer to the true dividend than in decentralized markets. In fact, for the same number of transactions, prices are typically further away from the true dividend value in the fully connected case, particularly when the public signal is wrong. In the case of no public signal, the fully connected market is

[14] Ruiz-Buforn et al. (2016) have already shown that the disclosure of an incorrect public information might drive market prices far from the market fundamentals, even in cases where the private information present in the market is sufficient to offset misleading public information. This suggest that traders have a tendency to overestimate the value of public information, or have a public information bias.

also farer from the fundamental, except only after a large number of transactions.

Figure 5 shows the average price in each market (dots), **as well as the estimation computed by local linear regression** (red lines), as a function of the number of private signals that suggest the dividend is 10.[15]. The nine panels refer to the different treatments. We can see that prices typically underreact to the information in the market and are closer to the prior of 5 than the fully revealing rational equilibrium expectation (given by the Bayesian prior). Under-reaction is significant except when the public information is correct and the effect is comparable across different connectivities.

Less unequal. The right panel of Figure 3 shows that wealth inequality is generally greater in centralized and in more connected markets. This is especially the case when the public information is not available or when it is incorrect, although in the latter there is a lot more variance across markets. In case the public information is correct, inequality is low and fairly similar across levels of connectivity. This is because agents are more homogeneously informed via the release of a correct public signal about the true value of the asset.[16]

This is again confirmed in the regressions in Table 5. The dummies of medium and low connectivity have significant effects both in the overall regression as well as in the case of no public information. In the case the public signal is available, the effects of connectivity are less significant. In the pooled regression in the first column, the dummy of correct public information has a negative, significant effect on the level of inequality whereas the dummy of incorrect public information has a positive, although not very significant, effect on inequality. The regressions also show, both overall and in all the split samples, that inequality is lower if the quality of the private information increases. The coefficient for the net number of correct private signals is always negative, albeit not always highly significant.

Why less trading and less unequal but not more inefficient? Decentralized or less connected markets, despite having lower trading volumes and less inequality, are generally not more inefficient. Although many traders have correct private information, and all

[15]We do not plot the market prices as a function of the Bayesian price itself as this is often indistinguishable from 0 or 10, given the large number of correct private signal in our setting

[16]A Mann Whitney test (two sample t-test) rejects the null hypothesis of equal median (equal mean) at 1 % significance level between HC-LC markets when there is no public information.

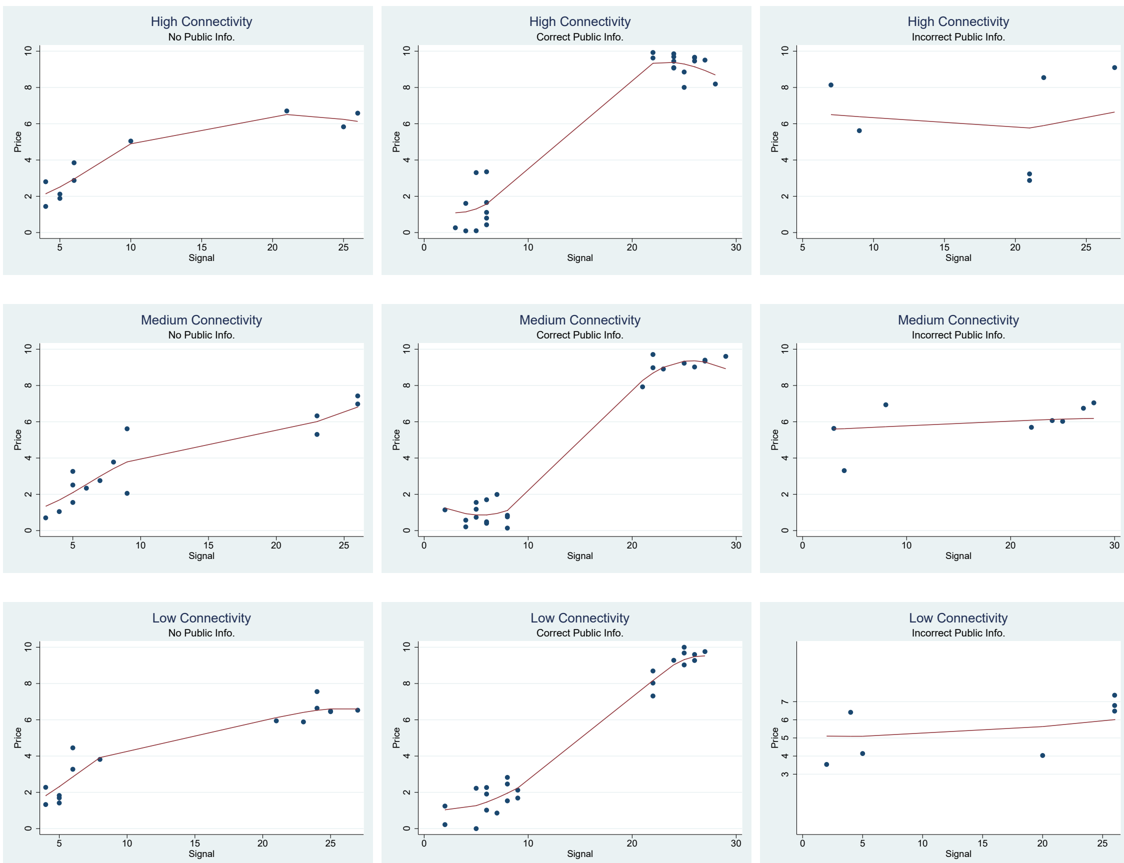


Figure 5: The curve displays the average price conditional on the Bayesian posterior in a market (E(Price| Bayesian posterior)). The estimation is computed by local linear regression, using Epanechnikov kernel bandwidth of 0.2. Signal is the no of signals that indicate the dividend is equal to 10.

Table 4: Market Inefficiency Estimations

	All	No Public Info.	Correct Public Info.	Incorrect Public Info.
Medium Connectivity	-0.175	-0.370^{***}	-0.100	0.464
	(0.211)	(0.016)	(0.221)	(0.817)
Low Connectivity	0.105	-0.036^{*}	0.355^{**}	0.453
	(0.176)	(0.012)	(0.119)	(0.815)
Correct Public Info.	-1.804^{***}			
	(0.109)			
Incorrect Public Info.	1.589^{***}			
	(0.239)			
Net Private Info.	-0.131^{***}	-0.199^{**}	$-0.058\dagger$	-0.225^{**}
	(0.027)	(0.029)	(0.034)	(0.057)
Constant	5.387^{***}	6.754^{***}	2.088^{**}	8.372^{***}
	(0.530)	(0.536)	(0.691)	(1.038)
Observations	129	39	69	21
R-squared	0.66	0.38	0.16	0.31

Market inefficiency is defined as the deviation of the price of each transaction from the realized dividend as in Equation 3. Low and medium connectivity are dummy variables where high connectivity is the base category. Correct and incorrect public information are dummy variables where no public information is the base category. The number of net correct private signals measures the difference between total number of correct and incorrect private information in a market. The standard errors corrected for market-level clustering, are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1, † p<0.15

traders observe each others' actions, higher number of transactions of centralised markets is not sufficient to improve on the revelation of the true fundamental value.

Notice that, conceptually, connectivity has two opposing effects on market efficiency and wealth distribution. On the one hand, information can propagate quicker through highly connected markets, reducing market inefficiency and profit opportunities from information asymmetry (which is the standard argument against OTC markets). But, on the other hand, higher connectivity not only allows but also induces (because of fear of competition) informed traders to trade faster with several counterparties and exploit further their information advantages before the information becomes fully incorporated into the price. This may not only increase trading volumes and wealth inequality but also reduce efficiency, as it is more likely to generate informational cascades. Our results show that the latter effect may be equally or more important than the former, thus associating higher connectivity to more volumes and inequality but not more efficiency.

Consistent with this, Table 6 shows that, although trading volumes under decentralization are lower in each of the three minute intervals, the reduction of trading volumes because of

Table 5: Market Inequality Estimations

	All	No Public Info.	Correct Public Info.	Incorrect Public Info.
Medium Connectivity	-0.015^{**}	-0.028^{***}	$-0.007\dagger$	-0.015
	(0.005)	(0.000)	(0.004)	(0.016)
Low Connectivity	-0.018^{***}	-0.033^{***}	-0.003	$-0.029\dagger$
	(0.005)	(0.000)	(0.002)	(0.017)
Correct Public Info.	-0.027^{***}			
	(0.005)			
Incorrect Public Info.	0.013^{*}			
	(0.006)			
Net Private Info.	-0.002^{***}	-0.004^{**}	$-0.001\dagger$	$-0.003\dagger$
	(0.001)	(0.001)	(0.000)	(0.002)
Constant	0.096^{***}	0.144^{**}	0.032^{**}	0.124^{***}
	(0.013)	(0.015)	(0.009)	(0.027)
Observations	129	39	69	21
R-squared	0.54	0.71	0.08	0.42

Market inequality is calculated with gini coefficient as explained in Equation 4. Low and medium connectivity are dummy variables where high connectivity is the base category. Correct and incorrect public information are dummy variables where no public information is the base category. The number of net correct private signals measures the difference between total number of correct and incorrect private information in a market. The standard errors corrected for market-level clustering, are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1, † p<0.15

decentralization decreases over time. As shown in the first three columns, the coefficients of medium and low connectivity are lower in absolute value in the regressions that use the volume in the second, and especially in the third, minute. Moreover, as shown in the last three columns, trading in the last minute, relative to the overall market volume, is significantly higher in decentralized rather than in centralized markets. The connectivity variables in the regressions on the volume ratio, defined as the fraction of trades in each minute, are positive and significant.

5.2 Determinants of the Distribution of Wealth

We now describe the main determinants of profits at the individual trader level and, thus, of wealth inequality across traders, comparing again centralized versus decentralized markets. We present regressions of profits, stock bought/sold/held and prices against individual and transaction-level variables as well as the market variables of the previous subsection. As behavior and performance at the individual level are highly dependent of the level of the dividend, we separate the observations by the realization of the dividend of the market.

Table 6: Market Trading Volume and Volume Ratio Estimations at each Minute

	Volume			Volume Ratio		
	Minute 1	Minute 2	Minute 3	Minute 1	Minute 2	Minute 3
Medium Connectivity	-15.263^{***}	-11.039^{***}	-4.142	-0.088^{**}	0.000	0.089^{**}
	(2.219)	(1.677)	(3.186)	(0.029)	(0.034)	(0.034)
Low Connectivity	-17.656^{***}	-15.143^{***}	-7.535^{***}	-0.058^{**}	-0.029^{***}	0.086^{***}
	(2.138)	(1.824)	(2.002)	(0.021)	(0.008)	(0.025)
Correct Public Info.	-5.088^{**}	-3.437^{*}	-2.917	-0.006	0.011	-0.004
	(2.124)	(1.808)	(2.235)	(0.029)	(0.019)	(0.029)
Incorrect Public Info.	-1.008	-1.440	1.928	-0.002	-0.024	0.026
	(2.445)	(1.648)	(2.262)	(0.032)	(0.018)	(0.027)
Net Private Info.	-0.525^{**}	-0.079	0.110	-0.006^{**}	0.002	0.004^{**}
	(0.185)	(0.143)	(0.091)	(0.002)	(0.002)	(0.002)
Constant	43.368^{***}	30.803^{***}	20.137^{***}	0.526^{***}	0.299^{***}	0.175^{***}
	(5.076)	(4.082)	(2.117)	(0.037)	(0.033)	(0.033)
Observations	129	129	129	129	129	129
R-squared	0.591	0.478	0.204	0.158	0.066	0.173

Volume (Minute 1, Minute 2 and Minute 3) show the number of transactions in each minute. Volume Ratio (Minute 1, Minute 2 and Minute 3) show ratio of transaction executed in each minute to the overall market volume. Low and medium connectivity are dummy variables where high connectivity is the base category. Correct and incorrect public information are dummy variables where no public information is the base category. The number of net correct private signals measures the difference between total number of correct and incorrect private information in a market. The standard errors corrected for market-level clustering, are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1, † p<0.15

Informed traders perform better, especially in the presence of connectivity

Table 7 shows the results of the profit regressions. In all columns, the effect of the variable informed agent is by far the most significant and quantitatively important variable, whereas the variable connected agent is never significant. In models 2 and 3 (columns three to six), we interact the informed agent variable with the level of overall market connectivity and, subsequently, with the variable being connected.[17] They show that being informed is important accross all treatments, especially in more connected markets, albeit the difference is often not significant. But, being informed is more important if the agent herself is also more connected than the rest of the agents of her market.

Centralization allows informed traders to trade faster in the right direction

Figure 4 show how the informed can exploit the uninformed relatively more in more connected markets. Focusing in the case of no public information, we compute the distribution of trans-

[17] In the fully connected market all agents are equally connected so connected agent only applies to the medium and low connected markets.

Table 7: Agent Profit Estimations

	Model 1		Model 2		Model 3	
	Dividend 0	Dividend 10	Dividend 0	Dividend 10	Dividend 0	Dividend 10
Informed Agent	20.375***	17.140***	28.661**	16.952*	28.657**	16.952*
	(3.846)	(3.653)	(9.145)	(7.465)	(9.150)	(7.468)
Informed Agent * Medium Conn.			−10.184	2.787	−13.177	1.355
			(10.036)	(8.889)	(10.241)	(8.630)
Informed Agent * Low Conn.			−13.092	−1.729	−18.443*	−4.284
			(9.396)	(8.845)	(9.910)	(8.832)
Connected Agent	0.849	−0.706	0.734	−0.614	−3.396	−2.596
	(1.314)	(1.385)	(1.460)	(1.238)	(2.635)	(2.474)
Informed Agent * Connected Agent					6.105**	2.967
					(2.526)	(2.063)
Medium Connectivity	−0.737	0.269	6.017	−1.651	8.126	−0.661
	(0.755)	(0.601)	(6.964)	(5.637)	(7.175)	(5.504)
Low Connectivity	−1.286	0.446	7.526	1.532	11.161†	3.222
	(1.155)	(1.187)	(6.446)	(5.774)	(6.904)	(5.942)
Correct Public Info.	0.138	0.048	0.118	0.070	0.170	0.044
	(0.259)	(0.155)	(0.246)	(0.158)	(0.269)	(0.170)
Incorrect Public Info.	0.051	−0.130	0.447	−0.190	0.703	−0.238
	(0.330)	(0.290)	(0.431)	(0.341)	(0.458)	(0.329)
Net Private Info.	−0.474***	−0.442***	−0.462***	−0.456***	−0.451***	−0.456***
	(0.092)	(0.095)	(0.091)	(0.093)	(0.090)	(0.093)
Constant	−4.562***	96.941***	−10.268*	97.311***	−10.523*	97.345***
	(1.026)	(0.802)	(5.220)	(3.753)	(5.203)	(3.757)
Observations	1,035	900	1,035	900	1,035	900
R-squared	0.11	0.10	0.12	0.10	0.12	0.10

Agents profits are the sum of the divdiend payment and the gains or losses generated by the trading activity. Informed agent is a dummy variable which takes a value of 1 if the subject has received two correct private signals. Connected agent is a dummy variable which takes a value of 1 if the number of edges it has (the degree) is above the median in that market. Low and medium connectivity are dummy variables where high connectivity is the base category. Correct and incorrect public information are dummy variables where no public information is the base category. The number of net correct private signals measures the difference between total number of correct and incorrect private information in a market. The standard errors corrected for market-level clustering, are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$, † $p<0.15$

actions of the informed/uninformed traders over time. That is, the figures display the total number of transactions up to time t relative to the total number of transactions by the closing of the market (averaged across all informed/uniformed agents across all markets). We include as columns the cases of the (i) buyers and dividend 0, (ii) buyers and dividend 10, (iii) sellers and dividend 0 and (iv) sellers and dividend 10. As rows, we include the case of centralized (highly connected) as well as the medium and low connected markets.

The figure shows that, in centralized markets (column 1), informed traders buy more slowly than uninformed traders when dividend is 0 and faster when the dividend is 10. Instead, they sell faster than uninformed traders when dividend is 0 and more slowly when the dividend is 10. These effects are much less aparent in decentralized markets (columns 2 and 3). All these results are confirmed by the Kolmogrov-Smirnov tests checking the equality of the distributions displayed in Table 8. The distributions of the informed agents (buyers and sellers) are significantly different than those of the uninformed in the centralized, highly connected, markets and

Table 8: KS Test Statistics for Equal Distributions

	Buyer		Seller	
	Dividend 0	Dividend 10	Dividend 0	Dividend 10
High Connectivity	0.1436^{**}	0.2210^{***}	0.2597^{***}	0.2980^{***}
Medium Connectivity	0.1105	0.1271	0.0940	0.0660
Low Connectivity	0.0939	0.1105	0.0939	0.0718

Two-sample Kolmogorov-Smirnov test is checking the equality of the distribution of the informed and uninformed traders' transactions. The test statistics are reported. *** $p<0.01$, ** $p<0.05$, * $p<0.1$, † $p<0.15$

insignificant in the medium and low connected markets.

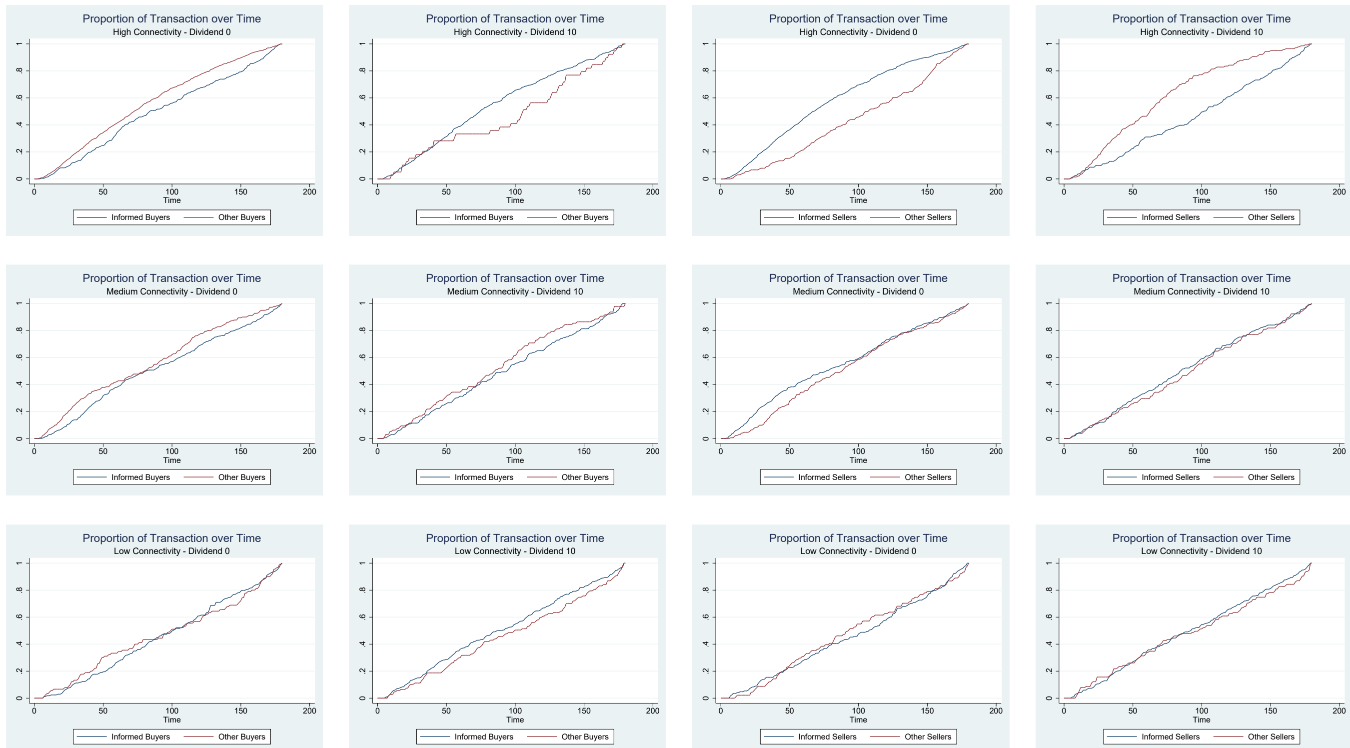


Figure 6: The figures display the total number of transactions up to time t relative to the total number of transactions by the closing time of the market (averaged across all informed/uninformed agents across all markets.

Informed also trade more in the right direction in more connected markets

We then decompose profits into stocks bought/sold/held and trading prices. In terms of the quantities traded, Table 9 shows that informed traders in centralized markets earn more profits by buying less stocks, selling more and thus holding less at the end of the market when the dividend payout turns out to be 0, and by buying more stocks, selling less and thus holding more at the end of the market when the dividend payout turns out to be 10. This is significantly less the case in decentralized markets, as the interaction variables between informed agent and medium/low connectivity always have the opposite sign, and they are highly significant. Notice that, in absolute value, the interacted effects almost cancel the main effect in most cases, and therefore the informed agents in decentralized markets trade in a similar way as the uniformed traders. All this takes into account the effects of the market variables described before.

Table 9: Agent Stock Bought, Sold and Holding Estimations

	Stock Bought		Stock Sold		Stock Holding	
	Dividend 0	Dividend 10	Dividend 0	Dividend 10	Dividend 0	Dividend 10
Informed Agent	-6.543^{***}	4.100^{***}	2.319^{***}	-2.772^{***}	-8.863^{***}	6.872^{***}
	(1.934)	(0.647)	(0.434)	(0.096)	(2.260)	(0.710)
Informed Agent * Medium Conn.	6.279^{**}	-3.602^{***}	-2.344^{***}	2.381^{***}	8.623^{***}	-5.984^{***}
	(1.958)	(0.718)	(0.506)	(0.469)	(2.253)	(0.951)
Informed Agent * Low Conn.	6.253^{**}	-2.894^{***}	-2.381^{***}	3.347^{***}	8.633^{***}	-6.241^{***}
	(1.960)	(0.765)	(0.447)	(0.537)	(2.279)	(0.756)
Connected Agent	0.453^{***}	-0.644	-0.314	-0.324	0.768^{*}	-0.320
	(0.129)	(0.548)	(0.235)	(0.306)	(0.349)	(0.812)
Medium Connectivity	-6.858^{***}	$1.148^{\dagger}$	-0.861^{**}	-2.965^{***}	-5.996^{***}	4.113^{***}
	(1.700)	(0.661)	(0.350)	(0.320)	(1.522)	(0.837)
Low Connectivity	-7.627^{***}	0.073	-1.307^{**}	-4.307^{***}	-6.319^{***}	4.380^{***}
	(1.694)	(0.506)	(0.426)	(0.397)	(1.521)	(0.856)
Correct Public Info.	-0.321	-1.399^{***}	-0.316	-1.412^{***}	-0.005	0.013
	(0.338)	(0.334)	(0.310)	(0.340)	(0.040)	(0.036)
Incorrect Public Info.	-0.146	-0.348	0.122	-0.414	$-0.268^{\dagger}$	0.066
	(0.689)	(0.280)	(0.559)	(0.308)	(0.151)	(0.124)
Net Private Info.	-0.014	-0.059^{*}	-0.067^{*}	0.016	0.053	-0.075^{**}
	(0.043)	(0.031)	(0.035)	(0.017)	(0.034)	(0.032)
Constant	10.310^{***}	4.280^{***}	5.462^{***}	7.429^{***}	14.847^{***}	6.851^{***}
	(1.774)	(0.711)	(0.897)	(0.523)	(1.234)	(0.680)
Observations	1,035	900	1,035	900	1,035	900
R-squared	0.08	0.08	0.14	0.11	0.06	0.06

Informed agent is a dummy variable which takes a value of 1 if the subject has received two correct private signals. Connected agent is a dummy variable which takes a value of 1 if the number of edges it has (the degree) is above the median in that market. Low and medium connectivity are dummy variables where high connectivity is the base category. Correct and incorrect public information are dummy variables where no public information is the base category. The number of net correct private signals measures the difference between total number of correct and incorrect private information in a market. The standard errors corrected for market-level clustering, are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$, † $p<0.15$

Informed do not trade at better prices in more connected markets Table 10 shows that, overall, informed traders do not trade at significantly different prices than the uninformed. The only signficant effect related to informed agents is that the informed end up paying a higher price as a buyer when the dividend is 10. Instead, in terms of the other important type of transaction (selling when the dividend is 0), informed agents sell at a lower price, although the effect is not signifcant. Overall, informed agents, both as buyers and sellers, do not trade at significantly different prices in more or less connected markets either. Finally, notice that prices tend to the fundamental as time goes by, that is they decrease when the dividend is 0 and increase when the dividend is 10.

5.3 Signal precision

We now compare the main results with relatively precise signals (probability of a correct signal equal to $q = 0.8$) with those in which the agents receive less precise signals ($q = 0.66$). We focus on the treatments with non-fully connected agents (medium and low connectivity) and no public information. Table 11 describes the results of the market level regressions as well as the regression on profits.

Notice that, as in the baseline results in the case of no public signal, highly decentralized markets exhibit less trading, more inefficiency but also less inequality than moderately decentralized markets. These effects are exhacerbated in the case of low precision signals. As it can be seen in the interaction between low connectivity and low precision in model 2, the difference is significant, and has the same sign as the main effect, in all cases (volumes, inefficiency and inequality).

As in the main results, being informed is a significant determinant of profits whereas being connected is not. Being informed is again more important in more connected markets, as the interactions with low connectivity are negative and significant in both regressions. Also as in the main results, being informed is more important if one is also connected, as the interaction is positive and significant (at 15% in the case of dividend 0). The importance of being informed as one is also connected is even stronger in markets with low precision, as coefficients of the triple interaction are positive and significant (at 15% in the case of dividend 10).

Table 10: Transaction Price Estimations

	Model 1		Model 2	
Variables	Dividend 0	Dividend 10	Dividend 0	Dividend 10
Informed Buyer	-0.187	0.216^{**}	-0.382†	0.359^{***}
	(0.137)	(0.092)	(0.232)	(0.053)
Informed Buyer * Medium Conn.			0.238	-0.213
			(0.272)	(0.268)
Informed Buyer * Low Conn.			0.562*	-0.249
			(0.276)	(0.194)
Informed Seller	-0.067	-0.025	-0.062	-0.087
	(0.157)	(0.146)	(0.315)	(0.173)
Informed Seller * Medium Conn.			0.223	0.052
			(0.428)	(0.206)
Informed Seller * Low Conn.			-0.342	0.184
			(0.358)	(0.306)
Connected Buyer	-0.593^{***}	-0.387†	-0.570^{***}	-0.386
	(0.112)	(0.235)	(0.105)	(0.245)
Connected Seller	0.016	0.002	0.007	0.002
	(0.114)	(0.214)	(0.118)	(0.220)
Time	-0.013^{***}	0.006^{***}	-0.013^{***}	0.006^{***}
	(0.002)	(0.002)	(0.002)	(0.002)
Medium Connectivity	-0.205	-0.025	-0.458	0.117
	(0.119)	(0.566)	(0.359)	(0.766)
Low Connectivity	0.076	-0.016	-0.017	0.064
	(0.168)	(0.495)	(0.267)	(0.593)
Correct Public Info.	-1.116^{***}	2.584^{***}	-1.098^{***}	2.590^{***}
	(0.125)	(0.123)	(0.129)	(0.125)
Incorrect Public Info.	3.198^{***}	-0.263	3.173^{***}	-0.264
	(0.225)	(0.773)	(0.221)	(0.763)
Net Private Info.	-0.155^{***}	0.104^{**}	-0.158^{***}	0.105^{**}
	(0.225)	(0.773)	(0.221)	(0.763)
Constant	6.956^{***}	3.950^{***}	7.065^{***}	3.832^{***}
	(0.718)	(0.884)	(0.777)	(0.933)
Observations	3,652	3,365	3,652	3,365
R-squared	0.513	0.429	0.516	0.430

Informed buyer/seller is a dummy variable which takes a value of 1 if the buyer/seller has received two correct private signals. Connected buyer/seller is a dummy variable which takes a value of 1 if the number of edges it has (the degree) is above the median in that market. Time shows the seconds in which that transaction occurs. Low and medium connectivity are dummy variables where high connectivity is the base category. Correct and incorrect public information are dummy variables where no public information is the base category. The number of net correct private signals measures the difference between total number of correct and incorrect private information in a market. The standard errors corrected for market-level clustering, are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1, † p<0.15

Table 11: Market and Agent Level Estimations with Signal Precision

	Volume		Inefficiency		Inequality		Profit	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Dividend 0	Dividend 10
Low Connectivity	-15.469^{***}	-10.039^{***}	0.417^{**}	0.352^{***}	-0.016^{*}	-0.005^{**}	7.337^{***}	7.881^{***}
	(2.524)	(0.542)	(0.097)	(0.026)	(0.005)	(0.001)	(0.355)	(0.521)
Low Precision	1.948	−12.876	0.075	-1.931^{**}	−0.003	−0.035	−1.106	−3.279
	(2.673)	(10.721)	(0.356)	(0.508)	(0.006)	(0.022)	(1.576)	(2.617)
Net Private Information	−0.834†	-1.736^{*}	-0.140^{**}	-0.218^{***}	−0.002†	-0.004^{**}	-0.681^{***}	-0.681^{***}
	(0.410)	(0.575)	(0.035)	(0.028)	(0.001)	(0.001)	(0.098)	(0.126)
Low Connectivity * Low Precision		-9.252^{***}		0.285^{***}		-0.019^{***}		
		(0.780)		(0.034)		(0.002)		
Net Private Info. * Low Precision		1.223		0.124^{**}		0.003		
		(0.649)		(0.030)		(0.001)		
Informed Agent							24.394^{***}	30.219^{***}
							(1.090)	(1.122)
Informed Agent*Low Conn.							-11.495^{***}	-7.716^{***}
							(0.693)	(0.888)
Informed Agent*Low Precision							4.575†	−3.671
							(2.305)	(3.456)
Connected Agent							1.463	−1.868
							(1.164)	(4.023)
Connected Agent*Low Conn.							−2.172	−7.889
							(1.426)	(4.252)
Connected Agent*Low Precision							-8.548^{*}	0.611
							(2.832)	(6.366)
Informed Agent*Connected Agent							4.318†	5.544^{**}
							(2.153)	(1.131)
Informed Ag.*Connected Ag.*Low Prec.							10.738^{**}	14.702†
							(3.269)	(7.297)
Constant	68.404^{***}	82.144^{***}	5.263^{***}	6.729^{***}	0.080^{**}	0.109^{**}	-5.607^{*}	93.967^{***}
	(5.686)	(10.267)	(0.719)	(0.494)	(0.014)	(0.019)	(1.796)	(2.038)
Observations	59	59	59	59	59	59	480	405
R-squared	0.41	0.46	0.42	0.45	0.34	0.41	0.15	0.25

This table only considers Medium and Low Connected Markets with High and Low Precision. Low Precision is a dummy variable that indicates the treatments where the private signals are correct 66% of the probability (q=0.66). High Precision Treatments are the base category where the private signals are correct at 80% of the probability (q=0.8). Volume, Inefficiency and Gini Coefficient are estimated at the market level, and profit is estimated at the agent level. Informed agent is a dummy variable which takes a value of 1 if the subject has received two correct private signals. Connected agent is a dummy variable which takes a value of 1 if the number of edges it has (the degree) is above the median in that market. Low connectivity is the dummy variable where medium connectivity is the base category. The number of net correct private signals measures the difference between total number of correct and incorrect private information in a market. The standard errors corrected for market-level clustering, are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1, † p<0.15

6 Conclusion

In the light of recent proposals to change the organization of asset trading on international markets, an assessment of the performance of decentralised markets, as compared to centralised ones, deserves more attention. The complexity of trading in decentralised markets makes it unsatisfactory to rely uniquely on simplified theoretical models. The unobservability of real markets' crucial variables, such as the fundamental value of a financial asset and the distribution of information among traders, makes it difficult to answer relevant questions through the use of field data. The experimental approach offers the advantage that traders' preferences, information and network structure can be exogenously controlled, while market efficiency and profits can be directly measured. Despite the economic relevance of decentralised markets, and the suitability of experimental work, very few experimental studies have explored the efficiency properties of decentralised markets, as compared to centralised markets.

Our results show that, despite having lower trading volumes, decentralized markets may not be more inefficient. Although information can propagate quicker through highly connected markets, reducing market inefficiency and profit opportunities from information asymmetry, higher connectivity induces informed traders to trade faster and exploit further their information advantages before the information becomes fully incorporated into the price. This not only increases trading volumes but also reduce efficiency, as it may generate informational cascades. We show that the latter effect may be equally or more important than the former, thus associating higher connectivity to more volumes but not more efficiency.

We also show that centralized trading, despite not being more efficient, it increases wealth inequality. As higher connectivity induces informed traders to trade relatively faster to exploit their information advantages, not only efficiency may be reduced, but wealth inequality may also be increased. We provide evidence that, in more connected markets, informed traders trade not only quicker but also more in the right direction, despite not doing it at better prices.

Our results thus challenge the conventional wisdom highlighting the informational inefficiencies of decentralized as compared to centralized markets, and are in line with some of the recent theoretical papers that emphasise the virtues of decentralization (Malamud and Rostek, 2017, and Glode and Opp, 2017). Our results should provide evidence against the criticisms of

OTC markets made by commentators and policy makers.

Our paper also contributes to the literature on insider trading by showing that superiorly informed traders are able to earn relatively larger profits in centralized markets. Thus, if regulators have concerns about the welfare of less informed investors, either because of inequality concerns or because these investors may ultimately exit the marketplace, our paper adds another concern about the outcomes of centralized markets. This is especially important given that, as shown in the paper, more egalitarian outcomes may not come at the expense of less efficient outcomes. Understanding the trading behavior of insiders can help in designing policies to detect insider trading and, more generally, to regulate securities markets.

The main objective of our analysis, and the proposed framework, is to understand and isolate the role of connectivity, a key difference between centralised and decentralised markets. But our results also show the virtues of a proposal for an "intermediate" market design, in which not all traders are connected to each other, as in decentralised markets, but trading occurs through a centralised market mechanism, as in centralised markets, rather than through the standard counterparty search and private bargaining of decentralised markets. As mentioned before, several platforms in the foreign exchange spot market, including Reuters, EBS, and Hotspot FX, already use a similar market design.

We show that this intermediate design can be optimal even if the market is liquid enough to allow for a fully centralised market. Indeed, we show that limiting the number of counterparties, if it does not increase the search costs, can decrease wealth inequality without reducing market efficiency. By reducing connectivity, the incentives to quickly exploit (and the fear of being quickly exploited by) information advantages can be reduced. Our proposed market design would allow traders to limit the number of partners with which to interact, as in decentralised markets, while maintaining anonymity, as in centralised markets. That would be an alternative to the dark pools, which some investors use to hide trades from the rest of the participants.

Of course, the reasons to limit trading with some market participants can be non-economic (e.g., social values) or economic (e.g. counterparty risk). The results of the paper would be directly relevant for the cases in which one selects counterparties for exogenous reasons, for instance because of corporate social responsibility. But one would need to add, and investigate how it interacts with ex-post trading, the ex-ante choice of trading partners in case of selection for economic reasons. This is a challenging task that we leave for further research.

Acknowledgements

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7 Appendix

Instructions for Experiments for "Fully/Highly Connected Markets (HC)" with no public information

This is an economic experiment on decision making in financial markets. The instructions are simple and if you follow them carefully, you can earn a considerable amount of money. Your earnings will be communicated to you privately, and paid in cash at the end of the experiment. During the experiment your earnings will be measured in points that will become € at the end of the experiment using a rate of €1 for every 50 accumulated points, plus a fixed amount of €3, as show-up fee for participating The corresponding amount in € will be paid in cash at the end of the experiment. At the beginning of the experiment each of you has been assigned a number. From now on, you and the rest of the participants will be identified by that number. No communication is allowed among the participants during the experiment. Any participant who does not comply will be invited to leave the experiment without payment.

The Market

The experiment consists of 15 periods of 3 minutes each. The market is composed of 15 participants. At the beginning of each period you will be randomly paired with another 14 participants. At the beginning of each period your initial portfolio consists of 10 assets and 1000 EU cash. Each participant has the same initial portfolio. In each period, you and the other participants will have the opportunity to buy and/or sell the assets. You can buy and sell as many assets as you want, although each bid, ask and transaction involves the exchange of one asset. Therefore, the assets are exchanged one at a time.

Information and Dividens

At the end of each period, you will receive a given dividend for the assets you hold in your portfolio. The value of the dividend can be 0 or 10 with the same probability. Thus, without additional information, the value of the assets can be 0 or 10 with a probability of 50%. Likewise, you will receive private information about the value of the dividend at the end of the period in the form of signals. If you receive:

- A private signal equal to 0 means that with a probability of 80% the value of the dividend will be 0 at the end of the period.

- private signal equal to 10 means that with a probability of 80% the value of the dividend will be 10 at the end of the period.

This will be your private information and therefore you will be the only one able to see it. At the end of each period, your profit will be the cash you have at the end of the period plus the dividends for the assets you own minus the 1000UE that is given to you at the beginning of the period. Your payment at the end of the experiment corresponds to the accumulated profit in all periods. If at any time you have any question or problem, do not hesitate to contact the experimentalist. Remember that it is important that you understand correctly the operation of the market, since your earnings depend both on your decisions and on the decisions of the other participants in your market.

Instructions for Experiments for "Medium/Low Connected Markets (MC, LC)" with no public information Welcome. This is an economic experiment on decision making in financial markets. The instructions are simple and if you follow them carefully, you can earn a considerable amount of money. Your earnings will be communicated to you privately, and paid in cash at the end of the experiment. During the experiment your earnings will be measured in points that will become € at the end of the experiment using a rate of €1 for every 50 accumulated points, plus a fixed amount of €3, as show-up fee for participating The corresponding amount in € will be paid in cash at the end of the experiment. At the beginning of the experiment each of you has been assigned a number. From now on, you and the rest of the participants will be identified by that number. No communication is allowed among the participants during the experiment. Any participant who does not comply will be invited to leave the experiment without payment.

<u>The Market</u>

The experiment consists of 15 periods of 3 minutes each. The market is composed of 15 participants connected to each other through a network. At the beginning of each period you will be paired randomly with a subset of participants. At the beginning of each period your initial portfolio consists of 10 assets and 1000 EU cash. Each participant has the same initial portfolio. In each period, you and the other participants will have the opportunity to buy and/or sell assets only with those participants with whom you are connected. You can buy and sell as assets as you want, although each bid, ask and transaction involves the exchange of a single asset. Therefore, the assets are exchanged one at a time.

Information and Dividens

At the end of each period, you will receive a given dividend for the assets you hold in your portfolio. The value of the dividend can be 0 or 10 with the same probability. Thus, without additional information, the value of the assets can be 0 or 10 with a probability of 50%. Likewise, you will receive private information about the value of the dividend at the end of the period in the form of signals. If you receive:

- A private signal equal to 0 means that with a probability of 80% the value of the dividend will be 0 at the end of the period.
- A private signal equal to 10 means that with a probability of 80% the value of the dividend will be 10 at the end of the period.

This will be your private information and therefore you will be the only one able to see it. At the end of each period, your profit will be the cash you have at the end of the period plus the dividends for the assets you own minus the 1000UE that were given to you at the beginning of the period. Your payment at the end of the experiment corresponds to the accumulated profit in all periods. If at any time you have any question or problem, do not hesitate to contact the experimentalist. Remember that it is important that you understand correctly the operation of the market, since your earnings depend both on your decisions and on the decisions of the other participants in your market.

Instructions for Experiments for "Medium/Low Connected Markets (MC, LC)" with public information

Welcome. This is an economic experiment on decision making in financial markets. The instructions are simple and if you follow them carefully, you can earn a considerable amount of money. Your earnings will be communicated to you privately, and paid in cash at the end of the experiment. During the experiment your earnings will be measured in points that will become € at the end of the experiment using a rate of €1 for every 50 accumulated points, plus a fixed amount of €3, as show-up fee for participating The corresponding amount in € will be paid in cash at the end of the experiment. At the beginning of the experiment each of you has been assigned a number. From now on, you and the rest of the participants will be identified by that number. No communication is allowed among the participants during the experiment.

Any participant who does not comply will be invited to leave the experiment without payment.

The Market

The experiment consists of 15 periods of 3 minutes each. The market is composed of 15 participants connected to each other through a network. At the beginning of each period you will be paired randomly with a subset of participants. At the beginning of each period your initial portfolio consists of 10 assets and 1000 EU cash. Each participant has the same initial portfolio. In each period, you and the other participants will have the opportunity to buy and/or sell assets only with those participants with whom you are connected. You can buy and sell as assets as you want, although each bid, ask and transaction involves the exchange of a single asset. Therefore, the assets are exchanged one at a time.

Information and Dividens

At the end of each period, you will receive a given dividend for the assets you hold in your portfolio. The value of the dividend can be 0 or 10 with the same probability. Thus, without additional information, the value of the assets can be 0 or 10 with a probability of 50%. You will receive additional information about the value of the dividend in the form of signals. All market participants will receive at the beginning of each period public information in the form of a public signal that will be correct with a probability of 80%, that is:

- A public signal equal to 0 means that with a probability of 80% the final value of the asset will be 0 at the end of the period.
- A public signal equal to 10 means that with a probability of 80% the final value of the asset will be 10 at the end of the period.

Recall that the public signal will be the same for all market participants. Likewise, you will receive private information about the value of the dividend at the end of the period in the form of two independent signals. If you receive:

- A private signal equal to 0 means that with a probability of 80% the value of the dividend will be 0 at the end of the period.
- A private signal equal to 10 means that with a probability of 80% the value of the dividend will be 10 at the end of the period.

This will be your private information and therefore you will be the only one able to see it.

At the end of each period, your profit will be the cash you have at the end of the period plus the dividends for the assets you own minus the 1000UE that were given to you at the beginning of the period. Your payment at the end of the experiment corresponds to the accumulated profit in all periods. If at any time you have any question or problem, do not hesitate to contact the experimentalist. Remember that it is important that you understand correctly the operation of the market, since your earnings depend both on your decisions and on the decisions of the other participants in your market.