



Limelight on dark markets: Theory and experimental evidence on liquidity and information [☆]



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ABSTRACT

We investigate how informational frictions affect trading in decentralized markets in theory and in a laboratory setting. Subjects, matched pairwise at random, trade divisible commodities that have different private values for a divisible asset with a common value (interpreted as money). We compare a bargaining game with complete information with a bargaining game where agents can produce fraudulent assets at some cost and are privately informed about the quality of their assets. The threat of fraud strongly reduces the subjects' ability to exploit the gains from trade, it reduces significantly both the size of the trade and the acceptability of the asset, but only a small fraction of all assets are actually fraudulent.

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1. Introduction

“Cognizability: by this name we may denote the capability of a substance for being easily recognized and distinguished from all other substances. As a medium of exchange, money has to be continually handed about, and it will occasion great trouble if every person receiving currency has to scrutinize, weigh, and test it. If it requires any skill to

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discriminate good money from bad, poor ignorant people are sure to be imposed upon. Hence the medium of exchange should have certain distinct marks which nobody can mistake (Jevons (1875, Chapter 5)).”

As far back as Jevons (1875), at least, it has been commonly accepted that a key property of a monetary asset – broadly defined as an asset that serves as a means of payment or collateral – is its *recognizability*, the fact that an asset can be authenticated at little cost. Throughout monetary history assets that lacked recognizability have been subjected to counterfeiting and fraud, e.g., the clipping of coins in ancient Rome and medieval Europe, and the counterfeiting of banknotes during the first half of the 19th century in the United States (Sargent and Velde, 2012; Mihm, 2007). More recently, problems arising from private information problems and fraud regarding collateral have played a crucial role in the unfolding of the 2007-08 financial crisis and the drying-up of liquidity in over-the-counter (OTC) markets, such as the market for bilateral repurchase agreements (repos).¹ According to Duffie (2012), p.2) private information problems are prevalent in decentralized asset markets with search and bargaining:

“An OTC bargaining game can be complex because of private information (...). The counterparties may have different information regarding the common-value aspects of the asset (for example, the probability distribution of the asset's future cash flows), current market conditions, and their individual motives for trade.”

The search-theoretic approach to monetary exchange (Shi, 1995; Trejos and Wright, 1995) and OTC trading (Duffie et al., 2005) provides theoretical foundations for decentralized markets – markets with pairwise meetings and bargaining – in which agents trade assets (e.g., money, real assets, financial securities) in the absence of private information.² This literature has been recently extended to introduce the possibility of counterfeiting and asset fraud and to analyze bargaining games under private information, e.g., Nosal and Wallace (2007), Li and Rocheteau (2011), Li et al. (2012), Hu (2013) and Shao (2014). These models have proven useful to explain how the threat of fraud affects the liquidity of assets (e.g., their acceptability and pledgeability) as well as the coexistence of assets with different rates of return – a puzzle in monetary theory. Moreover, they provide a simple narrative for the recent financial crisis – a class of assets became vulnerable to fraudulent practices, which reduced aggregate liquidity and led to a flight to quality.

There are two concerns with this theoretical literature, both of which can be addressed by an experimental approach. First, models of bargaining in decentralized markets with information frictions can generate multiple (perfect Bayesian) equilibria with different sets of predictions depending on how the equilibrium set is refined. The fact that equilibrium allocations are sensitive to the choice of the equilibrium concept generates a need to confront these theories with real observations. A second concern is the stark prediction of these models according to which counterfeiting is not an equilibrium phenomenon – it is an out-of-equilibrium threat – unless fraud is costless.³ This prediction of the theory has important policy implications as it suggests that measures to make media of exchange recognizable should be implemented irrespective of realized fraud. In actual economies, however, fraud and counterfeiting do happen.⁴ The experimental approach can help us understand if counterfeiting corresponds to a behavioral response to the possibility of fraud that is not captured by our model or whether it is an out-of-equilibrium phenomenon that vanishes as subjects learn about the environment.

The environment we implement in a laboratory setting is an extension of the decentralized market with random matching and bargaining under private information of Li et al. (2012), LRW thereafter. In contrast to LRW we impose linear payoffs, which makes the environment easier to apprehend for the subjects but also generates new insights for the effects of the threat of fraud on asset liquidity. Under a natural timing assumption, our modified bargaining game has a multiplicity of Perfect Bayesian Nash equilibria. To address this issue, we apply the *reordering invariance refinement* of In and Wright (2011) for signaling games with hidden actions. This refinement generates a limited set of equilibria that are payoff equivalent and all feature the same no-counterfeiting property. Relative to LRW, our game has the novel implication that it can generate equilibria with both limited pledgeability (i.e., agents only trade a fraction of their asset holdings) and partial acceptability of assets (i.e., a fraction of offers get rejected) – the two key dimensions of asset (il)liquidity.⁵ Moreover, equilibria feature a trade-off between trade sizes and acceptability – larger offers take longer to be accepted. Finally, we extend the theory to

¹ Prior to the 2008 crisis, asset-backed securities (ABSs) were used as collateral, and trillions of dollars were exchanged on the repo market without any extensive due diligence (Gorton and Metrick, 2010). When market participants realized that ABSs could be of dubious quality and the private information of asset holders became relevant, assets that had served as collateral were subject to prohibitive haircuts and liquidity in money markets dried up dramatically.

² Trejos and Wright (2014) provide a framework nesting the Duffie-Garleanu-Pedersen model of OTC trading and the Shi-Trejos-Wright model of monetary exchange.

³ This result holds for both signaling games where asset holders with private information make offers (e.g., Nosal and Wallace, 2007; Li et al., 2012; Hu, 2013) or screening games where the buyers of the asset are the ones to make offers (e.g., Shao, 2014). There are exceptions. Li and Rocheteau (2011) obtain counterfeiting in equilibrium by introducing some price posting in the Nosal-Wallace model. However, as shown by Shao (2014), this result is not robust if search is directed. Li et al. (2012) obtain counterfeiting in equilibrium in one extension of their model where the cost of fraud is random but offers cannot be made contingent on that cost.

⁴ For instance, in 2005, out of the \$760 billion of U.S. banknotes in circulation \$61 million of counterfeit currency was passed on to the public. See “The use and counterfeiting of United States currency abroad,” Part 3, page 47. Also, according to the estimate by Judson and Porter (2003) counterfeit U.S. currency that has been passed into circulation is about one note in ten thousands of currency in circulation.

⁵ Lester et al. (2011) can obtain the partial acceptability of assets in a related setting by assuming a cost to authenticate assets and accept an offer.

take into account fairness considerations that typically play a role in experiments, and we do so in a way that is consistent with a bargaining solution commonly used in monetary theory, namely, the proportional bargaining solution.

Our bargaining setting is a two-dimensional variation of an ultimatum game.⁶ The proposer is endowed with 100 notes and the responder is endowed with 100 widgets. While the widgets have a higher value to the proposer than the responder – thereby generating a motive for trade – the notes have the same terminal value for both agents, which allows them to transfer wealth across subjects and be used as media of exchange. The terminal value of the notes can vary across matches, and the proposer and the responder can be symmetrically, or asymmetrically, informed about these values. The bargaining game instructs the proposer to make a take-it-or-leave-it offer composed of a number of widgets for a number of notes to the responder.

We will study both a complete-information version of this game where the terminal value of the notes is common knowledge, and a private-information version where responders can produce fake notes at a fixed cost. In the perfect-information baseline, the terminal value of a note is \$0.1. A widget is worth \$0.1 to a responder and \$0.2 to a proposer, which implies a monetary gain from trading a widget equal to \$0.1. Hence, a proposer and a responder can generate at most \$10 in a match by exchanging the 100 widgets. We find that the subjects' behaviors in this setting are close to the predictions of the theory: Almost three quarters of all offers are accepted, most trades are individually rational, and are close to the Pareto frontier that would require all 100 notes to be traded. The subjects receive on average almost 60% of the maximum earnings in a match (\$10). The average price of a widget, defined as the number of notes exchanged for a widget, is 1.2 across accepted offers, above the unit price predicted by theory. This difference reflects standard fairness considerations found in the experimental literature on ultimatum games.

We study informational asymmetries by introducing two types of notes, blue and red notes. Blue notes are identical to the notes in the perfect information case; i.e., they pay off \$0.1 with certainty. In contrast, red notes are worthless, i.e., they pay off \$0. Responders cannot distinguish genuine from fraudulent notes; i.e., in the experiments they do not observe the color of the notes offered by the proposers. Each proposer is endowed with a \$10 account that is used to buy either 100 blue notes for \$10 or to buy 100 red notes at some commonly known dollar cost $C \leq 10$, keeping the remaining $\$(10 - C)$ in his account. Across sessions, we vary the cost of fraud from \$0 to \$10 by increments of \$2.

Key observations emerge from our study. (1) The threat of fraud adversely affects asset liquidity both in terms of the quantities offered in a match (a notion of pledgeability) and acceptance rates. In particular, the threat of fraud reduces the median quantities of notes and widgets offered relative to the perfect information benchmark, and these quantities are higher for higher costs of fraud. Furthermore, fewer offers are accepted under the threat of fraud than under perfect information, and the share of accepted offers increases monotonically with the cost of fraud. (2) The possibility of fraud only generates very small amounts of fraud when $C > 0$. In particular, for high costs of fraud ($C > 4$), less than 10% of offers involve fraudulent notes. This small amount of fraud does not vanish over time. In contrast, when fraud is costless ($C = 0$), about two thirds of offers involve fraudulent notes. (3) There is a signaling mechanism at work to prevent fraud. Blue-note offers tend to involve fewer notes and they tend to be accepted more often. (4) The threat of fraud has an adverse effect on realized gains from trade. Under the threat of fraud, the average earnings in a match can be as low as \$0.3, which is much lower than the approximate \$6 gain under perfect information. Moreover, even when fraud is small (less than 10% of all offers when $C = 6$) the average earnings are reduced by half. This finding is in accordance with the idea that policies that raise the recognizability of media of exchange, such as the ones typically implemented by Central Banks, are socially worthwhile even when the extent of fraud is limited.⁷

These observations are consistent with the theory developed in the paper. Observation (1) is consistent with the result according to which the threat of fraudulent practices makes asset markets illiquid by reducing the pledgeability and acceptability of assets. We find that the median number of notes offered in a match is in the interval predicted by the theory – between the cost of fraud (expressed in terms of genuine notes) and 100 – for all our treatments. Observation (2) is largely consistent with the no-fraud outcome of the theory according to which, when the cost of fraud is strictly positive, no fraud takes place in equilibrium. In our experiments very small amounts of fraud do occur, and the fraction of fraudulent notes increases as the cost of fraud decreases. This suggests that even small amounts of fraud can provide an indicator of the lack of recognizability of a medium exchange. Observation (2) is also consistent with the prediction that fraud can become significant when counterfeiting notes is costless. Observation (3) confirms the signaling mechanism in the theory according to which the proposer can signal the quality of his notes by retaining a fraction of them, and this fraction increases as fraud becomes cheaper. Finally, in theory the cost of fraud acts as an upper bound on the payment capacity of the subjects and, as a result, it reduces the sizes of the gains from trade that agents can exploit, in accordance with (4). When $C = 0$ the subjects should not be able to exploit any gains from trade, which is also in accordance with (4).

One of our concerns was the empirical validity of the equilibrium refinement. In order to test our equilibrium notion based on the *reordering invariance refinement* of [In and Wright \(2011\)](#), we studied two alternative timings for the order of the proposers' moves in the bargaining game under private information. In our reference game, the proposer chooses first to purchase blue or red notes, which is not observed by the responder. Following this choice, he is matched with a responder and he extends an offer

⁶ The decentralized market is directly inspired by the one used in monetary and financial economics ([Shi, 1995](#); [Trejos and Wright, 1995](#); [Duffie et al., 2005](#)): Individuals are matched bilaterally and at random, there are gains from trades due to differences in technologies and endowments, and the terms of trade are determined through a simple bargaining protocol. In contrast to these earlier models, we will assume that both commodities (widgets) and money (notes) are divisible as the divisibility of money matters for efficiency in monetary economies ([Berentsen and Rocheteau, 2002](#)) and is also key to allow signaling to take place under private information (e.g., [Nosal and Wallace \(2007\)](#)).

⁷ In terms of policies to improve the recognizability of the currency, the Federal Reserve and the US Bureau of Engraving and Printing redesign notes periodically and they run campaigns to inform the public about the new, distinctive features of notes. See, e.g., <http://www.newmoney.gov/>.

which can be accepted or rejected. This reference game has a continuum of Perfect Bayesian Nash equilibria because of the difficulty to pin down the responder's beliefs following out-of-equilibrium offers. We replicated our six experiments with varying costs of fraud for the following alternative sequence of moves. First, the proposer chooses an offer to make to the proposer once matched. Second, the proposer chooses to acquire blue or red notes, and simultaneously the responder accepts or rejects the offer. This latter game where observable actions happen first and hidden actions happen last, called the reverse-ordered game, can be studied with subgame perfection as the equilibrium notion, and it is used as a refinement in order to select a subset of the equilibria in the reference game. We find that the outcomes of the reverse-ordered games in terms of offers, acceptability, fraud, and gains from trade, are very similar to those of the original bargaining game. Hence, we conclude that it is a reasonable refinement for bargaining games in decentralized asset markets with private information.

1.1. Related literature

The search-theoretic literature on adverse selection in decentralized asset markets with pairwise meetings includes Cuadras-Morató (1994) on the emergence of a commodity money, Velde et al. (1999), and Burdett et al. (2001) on Gresham's law and Hopenhayn and Werner (1996) on the liquidity structure of asset returns. The search-theoretic literature on the role of money in the presence of moral hazard problems includes Williamson and Wright (1994); Li (1995); Trejos (1997, 1999), and Berentsen and Rocheteau (2004). In these models, signaling is not possible because money holdings are restricted to $\{0, 1\}$ or allocations are restricted to those that are pooling. Lester et al. (2011) describe a model with divisible assets, fiat money, and capital, where the recognizability problem takes the form of claims on capital that can be costlessly counterfeited and that are not accepted unless the buyer of the asset has the technology to authenticate them. Our theory builds on LRW who consider a model of an OTC market where assets are subject to costly fraudulent practices and solve the bargaining game under imperfect information.⁸

Our paper is related to the experimental literature on the role of goods and assets as media of exchange. This literature is reviewed in Duffy (2008), Section 4.1. Brown (1996) and Duffy and Ochs (1999) test the predictions of the search-theoretic model of Kiyotaki and Wright (1989) where the commodity that is used as money emerges endogenously. These studies suggest that the physical properties of commodities (e.g., their storage cost) matter the most for subjects' trading decisions. Duffy and Ochs (2002) study a similar environment where fiat money is added. Our paper emphasizes a different property of monetary assets: their recognizability. Finally, Duffy and Puzzello (2014) is the first attempt to bring the Lagos and Wright (2005) environment in a laboratory setting to test whether subjects use gift exchange rather than monetary exchange.

Our paper is also related to the experimental literature on (ultimatum) bargaining games under private information. Ultimatum games with asymmetric information include Kagel et al. (1996) where players have different information about each other's payoffs, and Mitzkewitz and Nagel (1993) where one subject is uninformed about the size of the gains from trade. Similarly, Forsythe et al. (1991) study a bargaining game where agents have asymmetric information about the gains from trade and interpret strikes as the failures of the bargainers to agree on a division of the surplus. For a review of experimental work on bargaining under incomplete information, see Camerer (2003).

Closer to what we do, Forsythe et al. (1999) consider an experiment where subjects are divided between buyers and sellers of assets, sellers hold assets of unknown quality, and buyers make offers that sellers can accept or reject. In contrast, in our model gains from trade arise because subjects can exchange a good of homogenous quality that they value differently, and we emphasize the role of an asset that is commonly valued across subjects as a medium of exchange. The private information problem takes the form of costly fraud, and we let the uninformed party make an offer, which opens up the possibility for signaling.

2. OTC bargaining game under perfect information

Our experiment aims to describe an OTC market where individuals are matched bilaterally and at random and bargain over the terms of trade.⁹ In each match, there are gains from trade due to different endowments and production technologies, and there is an asset playing the role of a medium of exchange. The bargaining game is a simple ultimatum game where the asset holder makes the offer.¹⁰ As shown in the monetary literature, under symmetric information this bargaining protocol maximizes the liquidity value of the asset.

The two players in the bargaining game are called *Proposer and Responder*.¹¹ The proposer is endowed with 100 units of a divisible asset called *notes*. These notes pay off a certain amount of a numéraire good at the end of the period. A key property of notes is that they yield the same payoff irrespective of who is holding them; i.e., their value is common to all

⁸ Additional models of OTC markets with private information include Rocheteau (2011), Camargo and Lester (2013), and Guerrieri and Shimer (2014).

⁹ In reality this OTC market can be a market for financial assets, as described in Duffie et al. (2005), or a decentralized market for goods and services, as in Shi (1995), Trejos and Wright (1995).

¹⁰ Our bargaining game differs from the standard ultimatum game in that offers are two-dimensional and realized gains from trade vary with the offers.

¹¹ In the context of the Shi-Trejos-Wright model, the proposer would be the *buyer* (of goods and services) and the responder would be the *seller*. In the context of the Duffie-Garleanu-Pedersen model, the proposer would be the *investor* with a high valuation for the (financial) asset, while the responder would be the *investor* with the low valuation for the asset.

participants.¹² However, notes might come in different qualities; i.e., they differ in the amount of the numéraire good that they pay off at the end of the period. Later on, we introduce private information, by assuming that individuals may have different information about the quality of these notes.

A responder is endowed with 100 units of an intermediate good called a *widget*. Proposers and responders have access to different technologies to produce the numéraire good from widgets. A proposer can produce two units of the numéraire good per widget, while a responder can only produce one unit of the numéraire good per widget. This difference in productivities generates gains from trade for proposers and responders.¹³

As a benchmark we consider the case where notes are homogenous and the proposer and the responder have perfect information about the terminal value of notes. The trading mechanism is such that the proposer (the note holder) makes a take-it-or-leave-it offer to the responder. An offer is a pair, $(\omega, n) \in [0, 100]^2$, where ω is the quantity of widgets received by the proposer from the responder and n is the quantity of notes delivered by the proposer to the responder. In the theoretical analysis we assume that all objects are divisible.

We assume that proposers and responders are risk-neutral. This approximation is justified under the expected utility paradigm when stakes are small (e.g., Arrow (1971), p.100).¹⁴ For proposers and responders alike, one note buys one unit of the numéraire good, and one unit of the numéraire good yields one utile. If a proposer offers the trade (ω, n) and if the trade is accepted, he receives ω widgets and keeps $100 - n$ notes. Accordingly, his payoff (in terms of the numéraire) is $U_P = 2\omega + 100 - n$. For the same trade, the responder keeps $100 - \omega$ widgets and receives n notes. Accordingly, his payoff is $U_R = 100 - \omega + n$.

Throughout this paper, we want to assess whether the trades that we observe in the laboratory satisfy basic requirements in terms of individual rationality, Pareto efficiency, and whether they accord with some standard equilibrium notion (e.g., subgame perfection). When we turn to the equilibrium, we will extend our model to introduce fairness considerations in the bargaining so that the predictions of the model are closer to the data.

Individual rationality. For a proposer, a trade that yields a positive surplus satisfies $2\omega + 100 - n \geq 100$; i.e., $S_P \equiv 2\omega - n \geq 0$. Accordingly, the set of individual rational trades for a proposer is

$$P \equiv \{(\omega, n) \in [0, 100]^2: 2\omega - n \geq 0\}. \quad (1)$$

For a responder, a trade that yields a positive surplus satisfies $100 - \omega + n \geq 100$; i.e., $S_R \equiv n - \omega \geq 0$. Accordingly, the set of individual rational trades for a responder is

$$R \equiv \{(\omega, n) \in [0, 100]^2: n - \omega \geq 0\}. \quad (2)$$

The set of feasible, individual rational trades is then $S = P \cap R$; i.e.,

$$S \equiv \{(\omega, n) \in [0, 100]^2: 2\omega \geq n \geq \omega\}.$$

The set S is depicted in Fig. 1 as the grey-shaded area. The curve labelled IR_P is the set of trades that yields zero surplus to the proposer; i.e., $2\omega = n$, and the one labelled IR_R is the set of trades that yield zero surplus to the responder; i.e., $\omega = n$. The first key benchmark for the experiments will be to assess whether the trades are in the set S , meaning that our subjects satisfy basic rationality assumptions.

Pareto efficiency. Our second key benchmark will be to assess whether the trades are Pareto-efficient.¹⁵ The Pareto frontier associated with this bargaining problem solves

$$S_P = \max_{\omega, n} (2\omega - n) \text{ s.t. } n - \omega = S_R, \quad (3)$$

and $(\omega, n) \in [0, 100]^2$. Pareto-efficient trades are such that the proposer offers all his notes ($n = 100$) and asks for $\omega \in [50, 100]$ widgets. The equation for the Pareto frontier in the utility space is $S_P + 2S_R = 100$. See the top quadrant of Fig. 2. So the proposer obtains a surplus equal at most to 100, while the maximum surplus of the responder is 50.¹⁶ The set of Pareto-efficient offers is represented in the bottom quadrant of Fig. 2.

¹² Engineer and Shi (1998, 2001) in environments with indivisible money and Berentsen and Rocheteau (2003) in an environment with divisible money emphasize the role of money to transfer utility perfectly across agents. In these models, fiat money allows traders to separate the decisions of how much to produce and how to split the resulting total surplus. Jacquet and Tan (2012) use a related argument to explain why fiat money has a higher liquidity than Lucas trees. In their model, Lucas trees that yield state-dependent dividends are valued differently by agents with different hedging needs. It follows that agents have an endogenous preference for money as a means of payment, because in contrast to Lucas trees they are valued equally by all agents.

¹³ In the context of the Shi-Trejos-Wright model, the utility of the buyer from consuming q units of goods would be $u(q) = 2q$, and the (opportunity) cost of the seller would be $c(q) = q$. Our model differs from the Shi-Trejos-Wright model in that the surplus of a match, $u(q) - c(q)$, is not strictly concave. However, the gains from trade are bounded above due to the finite endowment of the Responder. One can also interpret our assumptions in the context of the Duffie-Garleanu-Pedersen model. One can think of the widget as an asset that has a terminal value equal to 2. The Responder has no cost from holding the asset while the Proposer incurs a cost equal to one, for example, because of liquidity needs or hedging reasons.

¹⁴ For a critical discussion of this assumption, see Rabin (2000).

¹⁵ This property of the allocation corresponds to the pairwise core requirement in the mechanism design literature in monetary theory. See, e.g., Hu et al. (2009).

¹⁶ Notice that if proposers were not constrained by the number of notes they hold, e.g., they hold at least 200 notes, then the equation for the Pareto frontier would be $S_P + S_R = 100$ and all Pareto-efficient trades would be such that $\omega = 100$.

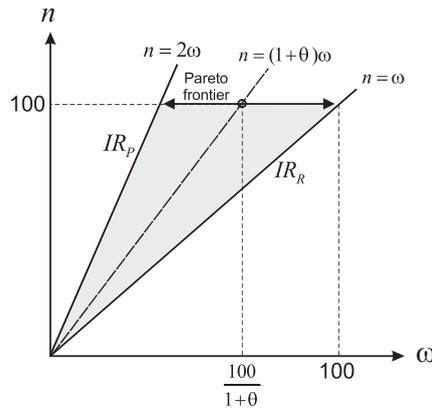


Fig. 1. Bargaining game under complete information.

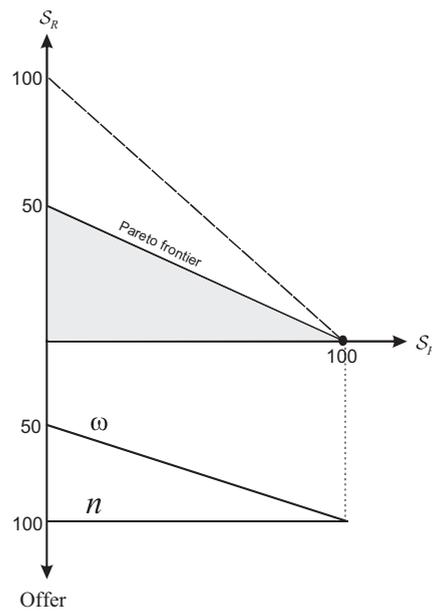


Fig. 2. Pareto frontier of the bargaining set.

Equilibrium under fairness. A third benchmark is to assess whether our subjects are able to coordinate on a subgame perfect equilibrium (SPE). In order to obtain a better representation of the experimental data, we extend our model to allow responders to value fairness. More precisely, we assume that the responder suffers a utility loss equal to $\theta/(1-\theta)$ times the surplus of the proposer, $S_P \equiv 2\omega - n \geq 0$, where $\theta \in [0, 1]$. The *motivation function* of the responder becomes

$$\hat{U}_R = \overbrace{U_R}^{\text{payoff}} - \overbrace{\frac{\theta}{1-\theta} S_P}^{\text{fairness loss}} = 100 + \frac{n - (\theta + 1)\omega}{1-\theta}. \tag{4}$$

Hence, the *behavioral surplus* of the responder is

$$\hat{S}_R \equiv S_R - \frac{\theta}{1-\theta} S_P.$$

In other words, in order to evaluate his own surplus the responder adopts as a reference point the surplus of the proposed scaled by some constant. For a responder to agree to a trade, $\hat{S}_R \geq 0$, his own surplus, $S_R \equiv n - \omega$, must be larger than $\theta/(1-\theta)$ times the surplus of the proposer.

Behavioral Assumption. Responders only accept offers that satisfy $S_R \geq \frac{\theta}{1-\theta} S_P$.

We directly incorporate this notion of fairness for three reasons.¹⁷ First, our formulation is equivalent to Kalai's (1977) proportional bargaining solution, which has been used extensively in the monetary literature. Second, a large body of experimental work finds that a concern for fairness is often present in bilateral bargaining.¹⁸ So incorporating fairness into our bargaining framework will help us to reconcile the theory with our experimental evidence. Third, the generalized model with fairness encompasses the standard model described so far, where $\theta = 0$. So, adding fairness will provide us with a wider range of predictions. Moreover, we will see that fairness can interact with informational frictions in interesting ways. For the theory, we will assume that θ is common knowledge in a match.

A utility maximizing proposer chooses a trade (ω, n) that maximizes his surplus, $2\omega - n$, subject to the constraint that the offer is fair to the responder; i.e., it is such that $S_R \geq \frac{\theta}{1-\theta} S_P$. Therefore, the proposer solves the following problem:

$$\max_{\omega, n} (2\omega - n) \text{ s.t. } n - \omega \geq \frac{\theta}{1-\theta} (2\omega - n), \quad (5)$$

and $(\omega, n) \in [0, 100]^2$. The solution is $n = 100$ and $\omega = 100/(1+\theta)$. It is marked by a circle on the Pareto frontier in Fig. 1. The proposer's surplus is equal to $(1-\theta) \times 100$, while the responder's surplus is $\theta \times 100$. As θ varies on $[0, 1]$, the outcome describes the whole Pareto frontier.

In what follows, we formulate Hypothesis 1, which contains the key predictions from the theory.

Hypothesis 1 (Symmetric Information). Under symmetric information (SI), proposers will offer 100 notes and ask for a number of widgets between 50 and 100.

3. OTC bargaining under the threat of fraud

We now consider a game based on LRW where the quality of the notes is chosen by the proposer. This model captures a situation where a con-artist may produce counterfeit notes or where a financial institution may originate and securitize bad loans that are sold afterwards to other investors.¹⁹ At the beginning of the game, the proposer has the choice between purchasing 100 blue (genuine) notes at the unit cost of one in terms of the numéraire or 100 red (counterfeit) notes at a total cost, C .²⁰ For proposers and responders alike, at the end of the game, one blue note buys one unit of the numéraire good, and, as above, one unit of the numéraire good yields one utile. Red notes are worthless, and responders cannot distinguish blue from red notes. To analyze this bargaining game with hidden actions, we adopt the methodology from In and Wright (2011) for signaling games with endogenous types.²¹ According to this methodology, one can look at a strategically equivalent game, the so-called *reverse-ordered game*. In this game, all observable moves are made first. In our context, in the reverse-ordered game the proposer chooses his offer first, and then he decides whether to acquire blue or red notes in order to execute his offer if it is accepted. The advantage of this methodology is that following an offer, there is a proper subgame that can be easily analyzed.²²

To see this, consider an arbitrary offer, (ω, n) , and suppose that this offer is accepted with probability p . Let η denote the probability that the proposer acquires blue notes after offering (ω, n) . It satisfies the following best-response function:

$$-100 + p(2\omega + 100 - n) + (1-p)100 \begin{cases} > \\ = \\ < \end{cases} -C + p2\omega \Rightarrow \eta \begin{cases} = 1 \\ \in [0, 1] \\ = 0 \end{cases}. \quad (6)$$

The left side of (6) is the proposer's expected payoff if he chooses to acquire blue notes: He pays 100 to purchase 100 blue

¹⁷ The direct incorporation of a preference for fairness is somewhat controversial among the profession. Here, we have chosen to do it in a way that is consistent with both the monetary literature, where the proportional bargaining solution has been used extensively (e.g., Aruoba et al. (2007)) and the experimental literature. Two well-known ways to incorporate fairness in bargaining models are presented by Bolton and Ockenfels (2000) and by Fehr and Schmidt (1999). Bolton and Ockenfels (2000) make an assumption related to ours where an agent's share in the total payoff of the game is an argument of the player's motivation function. Similarly, our assumption is consistent with the notion of equity aversion of Fehr and Schmidt (1999) if we set $\beta_i = 0$ (agents only care about inequity that is to their material disadvantage).

¹⁸ See Roth (1995) for a review of the bargaining literature and a discussion of studies that test this fairness hypothesis. In short, preferences for fairness are often present, but comparison of results from Ultimatum Game and Dictator games reveal that other factors such as negative reciprocity among responders and fear of negative reciprocity among proposers is also present. For simplicity, our formulation accounts for fairness alone.

¹⁹ For examples of fraud on media of exchange, see Li et al. (2012).

²⁰ As shown in Li et al. (2012) in the presence of a fixed cost of fraud we can restrict strategies with no loss in generality so that either all notes are blue or all are red but intermediate choices are ruled out.

²¹ We cannot apply standard refinements of signaling games, such as the intuitive criterion, because "types" are chosen in the initial stage instead of being determined by Nature. We instead apply the *reordering invariance refinement* of In and Wright (2011), based on the invariance condition of strategic stability from Kohlberg and Mertens (1986), which requires that the solution of a game should also be the solution of any game with the same reduced normal form. From a normative viewpoint, this refinement has the appealing property of selecting an equilibrium of the original game that yields the highest payoff to the proposer, the agent making the offer.

²² This key feature of the reverse-ordered game allows us to pin down beliefs following all out-of-equilibrium offers in a logically consistent way, and it improves tractability dramatically as subgame perfection becomes sufficient to solve the game.

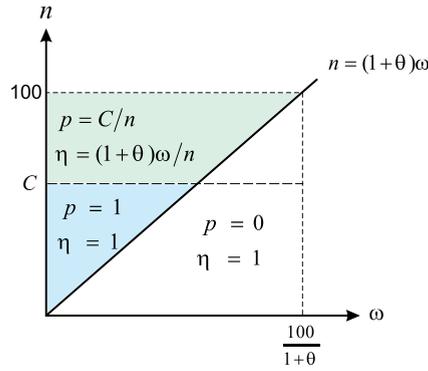


Fig. 3. Nash equilibria following an offer (ω, n) in the reverse-ordered game.

notes, with probability p his offer is accepted, in which case he receives ω widgets and keeps $100 - n$ notes, and with probability $1 - p$ the offer is rejected, in which case the proposer ends up with 100 blue notes. The right hand side of (6) is the expected payoff of the proposer if he acquires red notes: The cost of red notes is C , and with probability p the offer is accepted, in which case he receives ω widgets. The best-response function (6) can be rewritten as

$$pn \begin{cases} < \\ = C \\ > \end{cases} \Rightarrow \eta \begin{cases} = 1 \\ \in [0, 1] \\ = 0 \end{cases}. \tag{7}$$

The condition, $pn \leq C$, for the accumulation of blue notes can be interpreted as a liquidity or resalability constraint.²³ It states that for the proposer not to have incentives to acquire fraudulent assets, the expected value of the assets that are exchanged in a match has an upper bound, which is given by the cost to produce fraudulent assets.

The responder accepts an offer (ω, n) if $\mathbb{E}[\hat{U}_R] \geq 100$, where the expectation is with respect to the terminal value of the notes. Consequently, an offer is acceptable if $\mathbb{E}[S_R] \geq \frac{\theta}{1-\theta} \mathbb{E}[S_P]$, which is a generalization of our previous behavioral assumption to the case where the quality of the notes is uncertain.²⁴ If the responder believes the notes are genuine with probability η , then his best-response is

$$\eta n - \omega \begin{cases} > \\ = \frac{\theta}{1-\theta}(2\omega - \eta n) \\ < \end{cases} \Rightarrow p \begin{cases} = 1 \\ \in [0, 1] \\ = 0 \end{cases}, \tag{8}$$

since ηn is the expected value of the notes, and ω is the cost of giving up ω widgets. This best response can be re-expressed as

$$\eta n \begin{cases} > \\ = (1+\theta)\omega \\ < \end{cases} \Rightarrow p \begin{cases} = 1 \\ \in [0, 1] \\ = 0 \end{cases}. \tag{9}$$

Based on the best-response functions (7) and (8), the Nash equilibria of the subgame following an offer (ω, n) in the reserve-ordered game are represented in Fig. 3. If the proposer's offer is such that $(1 + \theta)\omega < n < C$, then the unique Nash equilibrium in the subgame following that offer is such that $p = 1$ and $\eta = 1$. Intuitively, if $n < C$, then from (7), it is optimal to set $\eta = 1$. If $\eta = 1$, then from (8) it is optimal to accept the offer; i.e., to set $p = 1$. Thus, if the value of the offered blue notes is less than the cost of fraud and if the responder's surplus is fair, then there is no fraud and the offer is accepted. If the proposer's offer is such that $n > C$ and $n > (1 + \theta)\omega$, then the equilibrium of the subgame following that offer involves mixed strategies. In this mixed-strategy equilibrium, the responder is indifferent between accepting or rejecting the offer and the proposer is indifferent between purchasing blue notes or red ones. In such a mixed-strategy equilibrium, $p = C/n$ and $\eta = (1 + \theta)\omega/n$. Intuitively, if $n > C$, then from (7), in order to induce the proposer to choose blue notes, we must have $p < 1$. Furthermore, if $n > (1 + \theta)\omega$, then from (8), in order to induce the responder to choose $p < 1$, we must have $\eta < 1$. An interesting property of this equilibrium is that as the number of notes offered increases, the probability of acceptance decreases and the probability of fraud increases. The results also show that fairness considerations interact with the private information friction. First, as θ increases, the set of offers associated with a positive level of trade shrinks. Second, in terms of the comparative statics of mixed-strategy equilibria, as θ increases, the probability of fraud decreases (i.e., η increases).

²³ If $pn > C$, then the proposer acquires red notes with certainty; i.e., $\eta = 0$.

²⁴ We kept the formalization of the fairness motive identical to the one under complete information. In particular, we treated the cost of fraud as sunk when measuring the expected surplus of the proposer. As before, the OTC bargaining game without fairness consideration is obtained by setting $\theta = 0$. This corresponds to the case studied in Li et al. (2012).

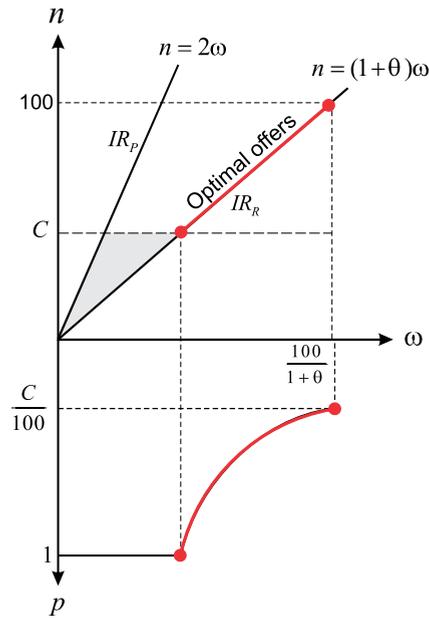


Fig. 4. Bargaining under the threat of fraud.

Intuitively, if the responder values fairness more, then the average quality of notes must increase in order to keep him indifferent between accepting or rejecting an offer.

Given the Nash equilibria of the subgames following all possible offers, the proposer at the beginning of the reverse-ordered game tree chooses the offer that maximizes his expected payoff. An optimal offer will not involve counterfeiting (unless $C=0$). To see this, suppose that the offer, (ω, n) , corresponds to a mixed-strategy equilibrium with $\eta = (1+\theta)\omega/n < 1$ and $p = C/n < 1$. The proposer could deviate and make an alternative offer, (ω', n') , with $\omega' = \omega$, but $n' < n$. Following such an offer, the Nash equilibrium would be such that $\eta' > \eta$ and $p' > p$, and hence the proposer would be better off since his payoff is $-C + p(2\omega)$.²⁵ The intuition for this no-counterfeiting result is that counterfeiting in equilibrium can never benefit the proposer given that it is fully anticipated by the responder. In fact, counterfeiting would harm the proposer by reducing his payment capacity. Using that $\eta = 1$, the optimal offer of the proposer solves

$$\max_{\omega, n, p} p(2\omega - n) \text{ s.t. } n - (1+\theta)\omega = 0 \text{ and } pn \leq C. \quad (10)$$

The proposer maximizes his expected surplus subject to two constraints. The first constraint is the participation constraint of the responder, where it is assumed that the responder believes that the notes are blue. The second constraint is the resalability constraint (7).

If $C < 100$, the resalability constraint is binding. In this case, the solution is $pn=C$, $n = (1+\theta)\omega$, $p \in [\frac{C}{100}, 1]$. This means that $(1+\theta)\omega = n \in [C, 100]$ as indicated in Fig. 4. If $n = (1+\theta)\omega = C$, the offer is accepted with probability one, but the proposer cannot purchase more $C/(1+\theta)$ widgets. The proposer can offer to sell a larger number of notes, but then his offer will be rejected with positive probability; i.e., $p < 1$. The result that, because of the threat of fraud, some offers can be rejected in equilibrium is new relative to LRW. The model, therefore, captures the notion that large note offers are less liquid and it shows that the private information problem affects both the intensive margin of trade, (ω, n) , and the extensive margin, the fraction of matches where a positive trade takes place.²⁶

Across all the optimal offers that solve (10), the expected surplus of the proposer is

$$\mathbb{E}[S_P] = p(2\omega - n) = \left(2\frac{\omega}{n} - 1\right)pn.$$

Using that $pn=C$, from the no-counterfeiting constraint, and $\omega/n = 1/(1+\theta)$, from the responder's participation constraint, the expected surplus of the proposer is $\mathbb{E}[S_P] = (1-\theta)C/(1+\theta)$. By a similar reasoning, the surplus of the responder is $\mathbb{E}[S_R] = \theta C/(1+\theta)$.

We illustrate the set of optimal offers in Fig. 4. The grey shaded area is the set of offers that satisfy the proposer's individual rationality constraint, the responder's fairness constraint, and the proposer's incentive compatibility constraint when $p=1$. Among this set of incentive-feasible offers, the preferred one of the proposer is $n = (1+\theta)\omega = C$. There are larger

²⁵ See Li et al. (2012) for a detailed proof.

²⁶ This property of our model differs from the version in (Li et al. (2012), Proposition 1) under strictly concave utility for the proposer in which equilibrium offers are always accepted with probability one.

Table 1
Experiment sessions.

Information setting	Session identifier	Treatment details	# Subj.	Avg. \$ ^a
Symmetric Informed	SI	Baseline, 100% blue notes	30	\$20.08
	MH ₁₀	Red notes cost \$10	34	\$16.60
	MH ₈	Red notes cost \$8	30	\$17.17
Moral Hazard	MH ₆	Red notes cost \$6	22	\$18.43
	MH ₄	Red notes cost \$4	30	\$16.55
	MH ₂	Red notes cost \$2	32	\$16.88
	MH ₀	Red notes cost \$0	20	\$17.30
	RMH ₁₀	Red notes cost \$10	30	\$18.90
	RMH ₈	Red notes cost \$8	30	\$18.77
Reverse-ordered	RMH ₆	Red notes cost \$6	22	\$17.89
	RMH ₄	Red notes cost \$4	30	\$16.93
Moral Hazard	RMH ₂	Red notes cost \$2	28	\$16.91
	RMH ₀	Red notes cost \$0	22	\$17.00

^a Includes \$7 show-up payment and single randomly-selected round.

offers, $n = (1 + \theta)\omega > C$, that are payoff equivalent, but they are rejected with a positive probability, $p < 1$. For instance, the proposer could make the perfect information offer, $n = (1 + \theta)\omega = 100$, but in this case the offer would be accepted with probability $p = \frac{C}{100} < 1$.

Finally, if fraud is costless, $C=0$, then no trade takes place in equilibrium, and proposers are indifferent between acquiring blue notes or red notes, $\eta \in [0, 1]$. Therefore, in this limiting case, fraud can emerge in equilibrium, but all offers should get rejected.

Hypothesis 2 (OTC bargaining game under the threat of fraud).

1. If $C=0$, fraud can occur, but no offer should be accepted.
2. If $C > 0$, then:
 - (a) No fraud takes place ($\eta = 1$).
 - (b) The minimum number of notes offered is C ($n \geq C$).
 - (c) Offers such that $n \geq C$ are accepted with probability $p=C/n$.
 - (d) The number of widgets offered is $\omega = n/(1 + \theta)$.

4. Experiment design

We conducted multiple experiment sessions at the UC Irvine Experimental Social Science Laboratory with 360 students as human subjects.²⁷ Students learned of experiments via posted advertisements and email announcements, and they registered to be subjects in the laboratory's subject pool through an online registration system. Days before each experiment session, an email was sent to a random selection of subjects in the pool notifying them of our upcoming session. Interested students then signed up for a specific session on the subject pool web site. Those who signed up received a reminder email about the session the day before it was conducted. Subjects received a \$7 show-up payment plus earnings based on the decisions made, with final take-home amounts rounded up to the nearest quarter. To compute these earnings, we assign \$0.1 for each blue note held by a proposer or a responder, and \$0.2 for each widget held by a proposer and \$0.1 for each widget held by a responder. Red notes have no value. The average take-home amount across all sessions was about \$17 for about 75 minutes of participation.

As shown in Table 1, these sessions are identified under the labels SI, MH, and RMH. We conducted a single, baseline session, labeled SI for Symmetrically Informed, in which both parties have common knowledge that all notes are blue. There are six Moral Hazard sessions, labelled MH₁₀, ..., MH₀, where the index indicates the costs in \$ of acquiring 100 red notes, $C \in \{10, 8, 6, 4, 2, 0\}$. (The cost of fraud in the theory section is expressed in terms of the terminal value of genuine notes.) In each of these sessions, proposers have to decide whether to buy 100 blue notes for \$10 or 100 red notes for \$C. Reverse-ordered Moral Hazard sessions are similarly labeled RMH₁₀, ..., RMH₀.

To facilitate the experiment's management, instruction, and data collection, we used the z-Tree software package (Fischbacher, 2007). Each session consisted of three stages: instruction, decision making, and questionnaire. During the instruction stage, subjects read about the decision-making scenario and answered questions to test their comprehension about the payoffs

²⁷ We here report results from thirteen sessions. Additional sessions were also conducted, but are not reported here. For instance, we ran six sessions with unrepeated one-shot games and found results roughly consistent with the results presented here. We also conducted sessions with symmetrically uninformed actors and sessions where the value of notes although privately known by the proposer is chosen by Nature. Some of these sessions are discussed below when interpreting our results.

associated with the different decision-making roles. After answering each question, the subject is told whether his or her answer was correct and is given a complete explanation of the correct answer. The instructions were identical across sessions except for changes in the description and questions that correspond to the specifics of the treatment.²⁸

The decision-making stage consists of twenty rounds of one-shot interactions.²⁹ Subjects are first randomly assigned to proposer and responder roles, which they maintain during all twenty rounds. They are then randomly and anonymously matched into the first one-shot interaction. After completion of the first round, the subjects were rematched randomly and anonymously for the second round, and so on for the rest of the twenty rounds. As typical in other experimental studies, behavior tends to converge after the early rounds. This fact can be seen in Fig. 5, which charts mean offer characteristics and acceptance rates during each session's duration. Our analysis below thus drops the first five rounds, and throughout this paper, we report statistics from the last 15 rounds.³⁰

At the end of the last round, the computer randomly selects one round, and all subjects are paid according to the decisions for that round. This one-round payment mechanism is widely used in experiments to best implement a one-shot decision. To ensure that each session ends on time, decisions were made with explicit time constraints. Proposers were given 120 s in rounds 1–3, and 45 seconds in all other rounds, or else the computer would make an offer of 0 notes for 0 widgets. Responders were given 60 s in rounds 1–3, and 30 seconds in all other rounds, or else the computer would reject the offer. This time constraint was never binding for responders, but the time limit was reached among some proposers. See the discussion below.

The questionnaire asks the subject to report personal information, such as sex, race, and academic major. A breakdown of self-reported subject characteristics by session as well as other statistics on subjects' behavior can be found in a supplement appendix available from the authors. The questionnaire data reveal a wide distribution of subjects, with higher proportions of female students, engineering and biological sciences students than in the university's undergraduate population.

5. Experiment results

We first present the experimental evidence on the outcomes of the OTC bargaining game under perfect information. The evidence is largely consistent with the theory once fairness considerations are taken into account. We then review the results for the OTC bargaining game with private information and the threat of fraud. Due to space considerations, we can only present the most important data analysis and findings. A supplement appendix, available from the authors, contains additional analyses and figures.

5.1. Perfect information (SI)

The SI session provides a benchmark relative to which we can assess the effects of informational frictions on market outcomes. We organize the presentation of the experimental evidence through a sequence of results characterizing the terms of the proposers' offers, responders' acceptance rates, and earnings. We start with a description of proposers' offers both in terms of quantities and prices.

RESULT #1 (Offers under perfect information). Under perfect information, the median number of notes offered is 100. The median offer price of a widget in terms of notes (n/ω) is larger than one.

The average number of notes offered is 87 out of 100; the median notes offered is 100 with 63% of proposers offering the full 100 notes.³¹ The fact that the median subject offers 100 notes is consistent with the assumption of Pareto-efficient trades. The median (average) widgets requested is 85 (74), well within the [50,100] range of Pareto-efficient trades. As seen in Fig. 5, offers come closer to the predicted behavior as the experiment progresses, suggesting that subjects are learning to make better offers. The median offer price is 1.14, the median price of accepted offers is 1.20, and the median price of rejected offers is 1.11. Every accepted offer has a price greater than or equal to 1, and accepted offers have, on average, higher prices than rejected offers (see Fig. 8).

²⁸ See the Supplemental Appendix for instructions for a representative session.

²⁹ Our setting extends the standard ultimatum game to a two-dimensional setting but where each party is given an initial endowment rather than just the proposer. The take-it-or-leave-it offers are standard in ultimatum games, though a literature with free-form, face-to-face discussion exists. See, for example, earlier experiments on Coasian bargaining, some of which also include risk or uncertainty (e.g., Hoffman and Spitzer (1982), Harrison and McKee (1985)).

³⁰ There is disagreement in the experimental literature about how to interpret the trials in a multi-round session. One interpretation is that the many trials of randomly-matched interaction in a single session constitute one observation. The idea is that the random matching creates an interdependence across rounds. An alternate view, which is a common view and the view we take in this paper, is that this linkage across rounds is sufficiently weak due to the large number of subjects in the session and the random payment scheme so that the different trials can be treated as separate observations. The interpretation has implications for the experimental design. Under the former view, the experiment calls for an increased number of sessions for a single treatment condition, usually with fewer subjects per session. Under the latter view, a single session with a large number of subjects provides a meaningful amount of data so that more treatment conditions can be conducted. Our experimental design thus reflects our preferred interpretation of sessions with random matching.

³¹ Given that the endowment of notes is 100, the possible offers have a downward bias relative to the subgame-perfect equilibrium offer of 100 notes for 100 widgets.

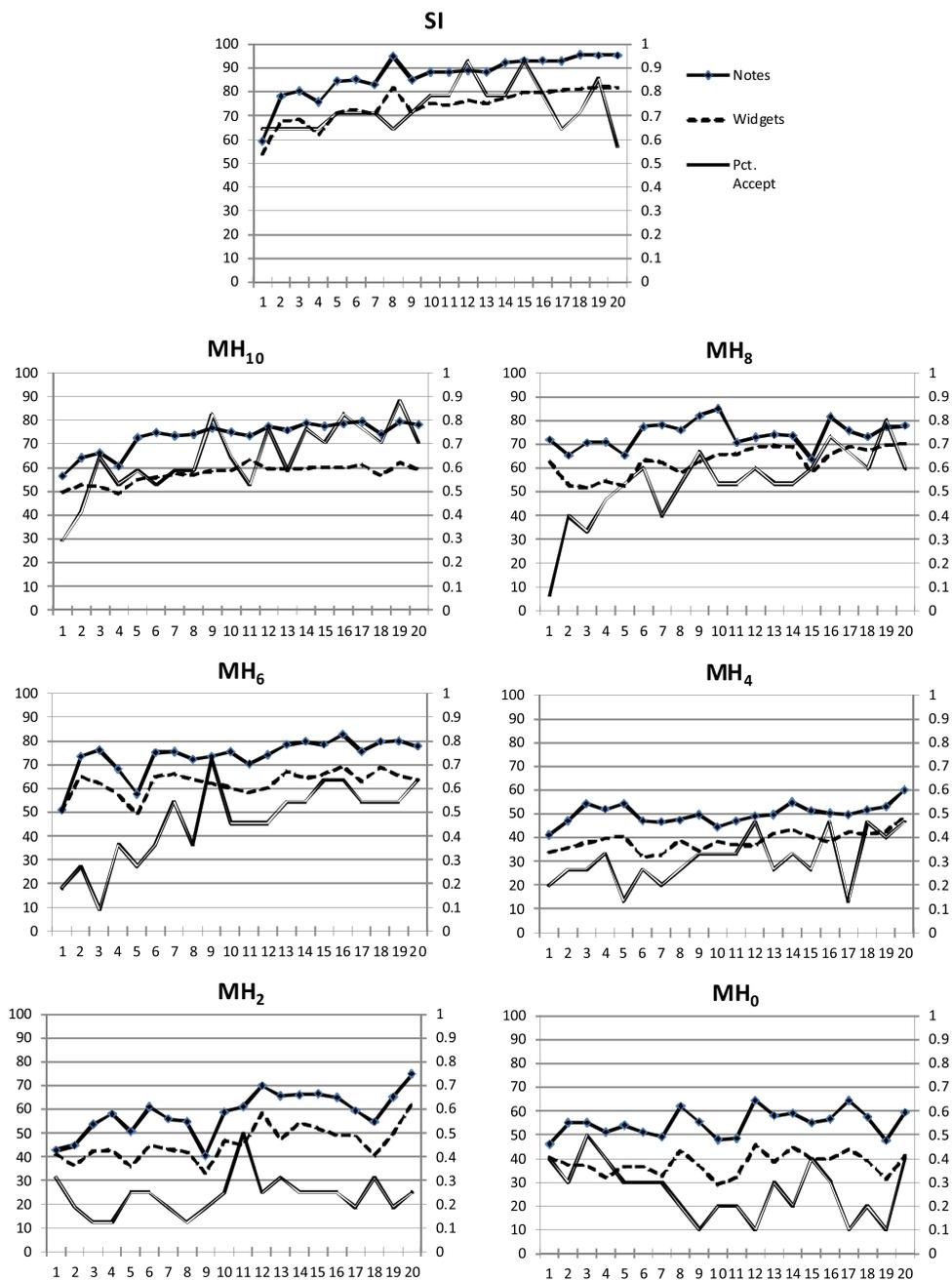


Fig. 5. Mean notes offered, widgets requested, and acceptance rate by round, SI and MH sessions.

RESULT #2 (Acceptance rate under perfect information). Under perfect information more than 76% of all offers are accepted.

The fraction of accepted offers is 76%, which shows a high level of successful trades.³² Some offers might be rejected, because subjects value fairness differently and the preference for fairness as captured by θ is private information, something we do not incorporate in our model. That accepted offers have, on average, higher prices lends support to this explanation.

³² As a comparison, [Duffy and Puzzello \(2014\)](#), who implement the Lagos-Wright model in the lab, obtain acceptance rates in bilateral matches between 40% and 50%. We attribute our relatively high acceptance rates to the following reasons. First, we chose linear payoffs (instead of strictly concave ones) that are easily computed, thereby minimizing the risk that subjects miscalculate incentive-compatible offers. Second, we do not have an additional stage where subjects have to choose their holdings of liquid assets (as in the original Lagos-Wright model). When we introduce such a stage (not in the paper), the acceptance rate falls to 64%. Third, subjects do not have to form beliefs about the redemption value of their notes, as they would have to do in an environment with fiat money.

Table 2
Summary statistics, moral hazard sessions^a.

	SI	High cost			Low cost		
		C=10	C=8	C=6	C=4	C=2	C=0
Blue Notes in %	100	96	96	92	78	72	36
Notes Offered	100	97	90	80	50	60	50
Widgets Requested	85	67	70	65	40	50	40
Acceptance rates in %	76	69	60	53	33	25	23
Accepted Price	1.20	1.33	1.25	1.25	1.43	1.50	1.50
Rejected Price	1.11	1.2	1.11	1.11	1.3	1.25	1.47

^a All entries are medians except for the % choosing blue notes and the % offers accepted.

We now turn to the ability of the subjects to exploit the gains from trade. Because the terminal value of a widget for a responder is \$0.1, while it is twice as large, \$0.2, for a proposer, each widget exchanged in a match generates earnings within a match of \$0.1. Given that the maximum number of widgets that can be exchanged is $\bar{\omega} = 100$, the maximum earnings (ME) from trading in a match are \$10. We will compare the average earnings observed in our experiments with the ME, bearing in mind that a trade can be Pareto-efficient even when earnings are less than the ME. We will also describe how the average earnings are divided between the proposer and the responder. The earnings of a responder are $\$0.1(n - \omega)$ and the earnings of a proposer are $\$0.1(2\omega - n)$, and so the total earnings are $\$0.1\omega$. Accordingly, the earnings share of a proposer is $2 - n/\omega$ and the earnings share of a responder is $n/\omega - 1$, where n/ω is the price of widgets in terms of notes.

RESULT #3 (Earnings under perfect information). Under perfect information the subjects receive on average 58.6% of the maximum earnings of \$10. The average earnings share of responders is 19%.

This surplus is split unequally: The average earnings for proposers and responders are \$4.74 and \$1.12, respectively. Conditional on trading, the average match realizes 78.9% of the ME. Finally, the average earnings share of responders is 19%. Altogether, the average earnings are below maximum earnings for two reasons: First, a quarter of all offers are rejected; second, conditional on a trade, about 20% of all widgets remain in the responders' hands.

Summary of Perfect Information (SI). Results 1–3 suggest that the behavior of the subjects is largely consistent with Hypothesis 1: Most offers are accepted and most trades are Pareto-efficient. The outcome differs from the SPE outcome according to which the entire match surplus is captured by the proposer. Furthermore, some offers with a positive surplus are rejected. Both observations are consistent with the notion that subjects value fairness, as typically observed in ultimatum games (Güth and Kocher, 2013).

5.2. Moral Hazard (MH)

Table 2 summarizes key statistics from our MH sessions. For the discussion that follows, it is useful to distinguish between sessions with low costs of counterfeiting, $C \leq 4$, and sessions with high costs of counterfeiting, $C \geq 6$, as sessions in each group share similar characteristics. Recall that if $C=10$, then acquiring blue notes is a weakly dominant strategy, because blue and red notes are equally costly, but blue notes have a higher redemption value than red ones. Moreover, it is strictly optimal for the proposer to acquire blue notes if he believes that there is a positive probability that his offer will be rejected. In the opposite case where $C=0$, acquiring red notes is a weakly dominant strategy, and it is strictly optimal if the proposer believes that there is a positive probability that his offer will be accepted.

The following result provides stylized facts for offers both in terms of quantities (note offer, n) and prices (notes per widget, n/ω).

RESULT #4 (Offers under the threat of fraud). The median number of notes offered is lower under the threat of fraud than under perfect information ($n < 100$ for all C), and it is higher for a high cost of fraud ($C \geq 6$) than a low cost of fraud ($C \leq 4$). Median prices are higher for a low cost of fraud than a high cost.

The cost of fraud affects the quantities traded (n and ω) and prices (n/ω) in accordance with theory. The median note offer and the median widget request are lower in the low-cost sessions than in the high-cost sessions. The median note offer decreases non-monotonically from $n = 97$ ($C=10$) to $n = 50$ ($C=0$), and the median widget request also decreases non-monotonically from $\omega = 67$ ($C=10$) to $\omega = 40$ ($C=0$).

For $C=10$, the median note offer, $n=97$, is close to its complete-information level, $n=100$. The median widget request, however, is lower, $\omega = 67$ instead of $\omega = 85$, suggesting that prices are higher to compensate sellers for the residual uncertainty about the quality of notes. In contrast, when fraud is costless, $C=0$, the median note offer and the median widget request plummet to $n=36$ and $\omega = 50$. Thus, the possibility of fraud has a dramatic effect on the intensive margin of trade when fraud is costless.

In theory (see Hypothesis 2), the optimal note offer should be between $10C$ and 100 . If the offer is $10C$, then the offer is accepted with certainty, and if the offer is strictly larger than $10C$, the offer is accepted with some probability less than one.

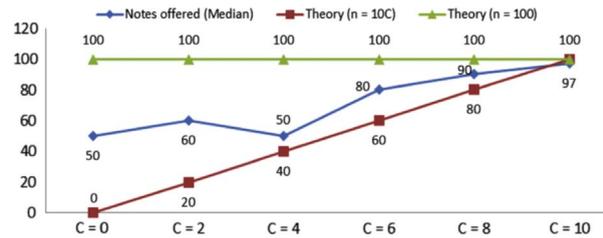


Fig. 6. Median notes offered, MH Sessions.

The acceptance probabilities are such that all offers are payoff equivalent, from the proposer's viewpoint. Fig. 6 plots the theoretical boundaries for the offers – the red line (with squares) is the lower bound, $10C$, while the green line (with triangles) is the upper bound, 100 – and the medians from the experiments (the blue line). The medians of the note offers are located between the theoretical boundaries for $C = 0, 2, 4, 6, 8$.

The median (accepted) price is higher in low-cost sessions ($n/\omega \geq 1.43$) than in high-cost sessions ($n/\omega \leq 1.33$). This pattern also holds for rejected offers and if we separate blue-note and red-note offers. However, prices are barely affected within high-cost sessions and low-cost sessions. Furthermore, the median price of accepted offers is higher than the median price of rejected offers across all sessions. This finding is consistent with the SI session where responders require a minimum expected surplus in order to accept an offer. The minimum acceptable price to the responder in high-cost sessions is close to the one under perfect information (between 1.11 and 1.2). This reservation price increases significantly in low-cost sessions.

To formally test whether offers change as the cost of fraud changes, we conduct a nonparametric statistical analysis. Standard tests of differences in offers across treatments are problematic, because the offers are bounded with many offers at the boundary of $n = 100$. Typical distributional assumptions will thus not be appropriate. We instead conduct a nonparametric bootstrapping procedure to test differences across treatments. From the set of m experimental observations for a session, we draw with replacement a new sample of m observations.³³ We then calculate the statistic of interest (e.g., mean) for this new sample, and repeat the procedure 10,000 times for each session to obtain a pool of statistics (e.g., 10,000 means). After repeating this procedure for each session, we take the first statistic from two different sessions (e.g., MH_8 and MH_2), calculate the difference between the two statistics, and then repeat for the rest of the statistics from each session to construct a distribution of differences with which to make statistical inferences.

Fig. 7 displays the difference distributions for MH_{10} - MH_0 for notes offered and price. These two sessions represent the starkest difference in cost for the MH sessions. The 99% confidence intervals marked by dotted lines reveal that the difference in mean note offers between MH_{10} and MH_0 is positive with high statistical significance, and the difference in price is negative with high statistical significance. Table 3 provides the nonparametric confidence intervals for mean note offers and mean price for all SI and MH session comparisons. For mean note offers, we do not always find statistical differences when comparing sessions with small differences in C , but we typically find statistical differences for sessions with large differences in C . Observed prices exhibit greater variance, yet a similar pattern is found: The mean prices are statistically different across sessions with large differences in C . Overall, the nonparametric analysis provides formal statistical evidence that offers sizes decrease and prices increase in response to a growing threat of fraud. This result has implications for policy analysis as it shows that any measure that raises the cost of producing fraudulent means of payment has the potential to increase the volume of trade.

RESULT #5 (Acceptance rates under the threat of fraud). Fewer offers are accepted under the threat of fraud than under perfect information. Moreover, the share of accepted offers falls monotonically from 69% ($C = 10$) to 23% ($C = 0$).

We first discuss the case when fraud is costless. For $C = 0$, a key prediction of Hypothesis 2 is that when the cost of producing fraudulent (red) notes approaches zero, notes become illiquid and no longer serve as a means of payment. In accordance with this prediction, when notes can be counterfeited at no cost in session MH_0 , about 75% of offers are rejected. This result provides a stark example of asset illiquidity generated by the threat of fraudulent practices. It is still surprising that there is trade taking place, given that producing fraudulent notes is a weakly dominant strategy. This observation can be rationalized by the fact that 36% of offers involved blue notes. Why some proposers acquired blue notes if they expected responders to accept offers is unclear but may be due to preferences concerning non-monetary considerations by the subject, such as honesty or fairness, that are not commonly known.

We next discuss the intermediate cases $C = 2, 4, 6, 8$. In theory (see Hypothesis 2), if $n \leq 10C$, then the offer is accepted with certainty, $p = 1$, whereas if $n > 10C$, then the offer is accepted with probability $p = 10C/n < 1$. As shown above, the median note offer is typically above $10C$, and hence in theory it should only be partially accepted. If we compute the theoretical acceptance rate for the median offer, $p^{\text{theory}} = 10C/n$, we find $p^{\text{theory}} = 1/3, 4/5, 3/4, 8/9$ for $C = 2, 4, 6, 8$. See Table 4. These theoretical acceptance rates tend to increase with the cost of fraud, in accordance with the experimental evidence. However, theory over-predicts

³³ For most variables of interest (price, acceptance rate, blue notes rate, etc.), all observations are used. Because price can be undefined if 0 widgets are requested, we only use those observations in which the widgets requested is not 0.

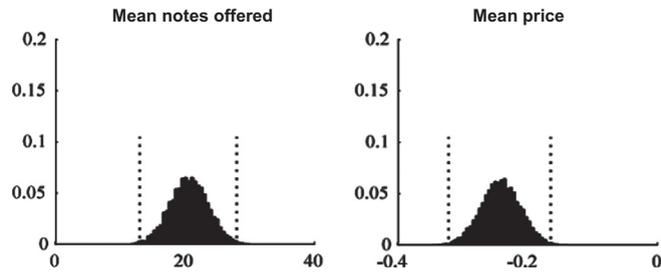


Fig. 7. Nonparametric difference distributions, $MH_{10}-MH_0$.

Table 3
99% Confidence Intervals for Difference in Means, SI and MH Sessions.

Notes offered							
	MH_{10}	MH_8	MH_6	MH_4	MH_2	MH_0	
SI	[7.66,20.89]*	[8.65,20.68]*	[8.04,19.95]*	[33.86,46.92]*	[23.30,35.27]*	[28.14,41.41]*	
MH_{10}		[-6.80, 7.44]	[-7.05, 6.52]	[18.41,33.62]*	[7.99,21.92]*	[13.02,27.96]*	
MH_8			[-7.11,5.89]	[18.53,32.79]*	[8.12,21.25]*	[12.88,27.38]*	
MH_6				[19.47,33.07]*	[8.79,21.57]*	[13.66,27.74]*	
MH_4					[-18.02, -4.05]	[-12.87, 2.10]	
MH_2						[-1.46, 12.50]	
Price							
	MH_{10}	MH_8	MH_6	MH_4	MH_2	MH_0	
SI	[-0.15,-0.08]*	[-1.96,0.01]	[-0.11, 0.01]	[-0.60,-0.07]*	[-0.26,-0.09]*	[-0.43,-0.28]*	
MH_{10}		[-1.84, 0.13]	[0.00,0.13]*	[-0.49, 0.05]	[-0.15, 0.03]	[-0.32,-0.17]*	
MH_8			[-0.07, 1.90]	[-0.49, 1.77]	[-0.21, 1.80]	[-0.38, 1.60]	
MH_6				[-0.55,-0.01]*	[-0.22,-0.02]*	[-0.39,-0.22]*	
MH_4					[-0.12, 0.44]	[-0.30, 0.26]	
MH_2						[-0.30,-0.08]*	

* denotes significantly different from 0 at 99% level.

the acceptance rate, which was also the case under perfect information. Our nonparametric analysis (see the supplement appendix) generally finds the decrease in the acceptance rate as C drops to be statistically significant.

The previous results show that subjects do trade under the threat of fraud. For all $C > 0$, there are least 25% of all offers that are accepted and the median number of notes offered does not fall below 50. So trade is resilient to the threat of fraud, i.e., the market does not shut down.

Finally, we discuss the case when fake notes cost the same as genuine notes, $C=10$. Theory predicts that offers should be attributed to blue-note holders and hence should be accepted with certainty. In our experiment, only 69% of all offers are accepted, which is less than the 76% under perfect information. This could be explained by the fact that 4% of proposers chose red notes with the result that some subjects received red notes, which might have made them more cautious in their acceptance strategy.

RESULT #6 (The extent of fraud). When fraud is costless, $C=0$, 64% of offers involve fraudulent notes. When fraud is costly, $C \geq 2$, more than 72% of offers involve genuine notes, and when $C \geq 6$, more than 92% of offers involve genuine notes.

A stark prediction of the theory (Hypothesis 2) is that no fraud takes place in equilibrium if fraud is costly, $C > 0$. Intuitively, if fraud is correctly anticipated, then it is not beneficial to the proposer and hence it should not happen. In the lab, as in actual economies, some fraud takes place.³⁴ However, in high-cost sessions, the fraction of fraudulent notes is less than 8%, which we view as remarkably consistent with a no-fraud equilibrium. Even for low costs of fraud, $C=2,4$, the share of blue-note offers is large (72% and 78%). Moreover, fraud is monotonically increasing as the cost of counterfeiting decreases from 4% ($C=10$) to 64% ($C=0$), and this decline is statistically significant. So, while broadly consistent with the theory, the experimental evidence is more nuanced than the sharp no-counterfeiting result.

³⁴ The no-fraud proposition is also at odds with real-world evidence. Counterfeiting has been documented for all major currencies. In 2005 in the U.S., \$61 million of counterfeit currency was passed on to the public, 3717 counterfeiters were arrested, and 611 counterfeiting plants were suppressed. See United States Treasury Department (2006). As documented by Mihm (2007), counterfeiting was a widespread phenomenon in the U.S. during the 19th century.

Table 4
Comparison with theory^a.

	C=10	C=8	C=6	C=4	C=2	C=0
Median n	97	90	80	50	60	50
Median ω	67	70	65	40	50	40
p^{data} in %	69	60	53	33	25	23
p^{theory} in %	100	89	75	80	33	0

^a All entries are medians except for the acceptance rate.



Fig. 8. Offered notes, acceptance, and prices by type of notes, MH sessions.

RESULT #7 (Note retention as a signaling mechanism). Blue-note offers tend to involve fewer notes and a lower price than red-note offers, and they tend to be accepted more often.

The top panel of Fig. 8 compares offers made by proposers with blue notes and proposers with red notes. Except for $C=10$, where the fraction of red-note holders is only 4%, blue-note proposers consistently offer fewer notes than red-note proposers. This finding is consistent with the result from the adverse-selection literature according to which individuals can signal the quality of their assets, and hence obtain better terms of trade, by retaining a fraction of those assets (see, e.g., DeMarzo and Duffie (1999), and Rocheteau (2011)). It is also consistent with a Gresham's Law outcome according to which bad monies (red notes) drive good monies (blue notes) out (see, e.g., Velde et al. (1999)).

As the cost of counterfeiting decreases from $C=10$ to $C=0$, the acceptance rate for blue notes decreases from 97% to 28%, while the acceptance rate of red notes decreases from 50% to 20%. As shown in the middle panel of Fig. 8, blue-note holders seem to successfully signal the quality of their notes as the acceptance rates for blue notes are higher or equal to those for red notes in five out of six MH experiments (the exception is the session with $C=6$).

The bottom panel of Fig. 8 shows that the price offered by red-note holders is always higher than the price offered by blue-note holders. This is again consistent with a signaling mechanism according to which the individual with high-quality assets retains some of his assets but asks for a better price. Alternatively, it might be that red-note holders were simply attempting to induce responders to accept their proposals by offering higher prices for widgets. If this was the case, these

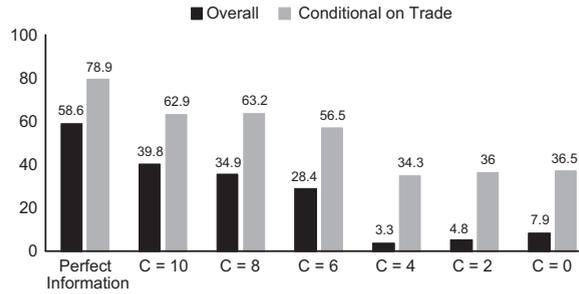


Fig. 9. Average earnings as percentage of ME, SI and MH sessions.

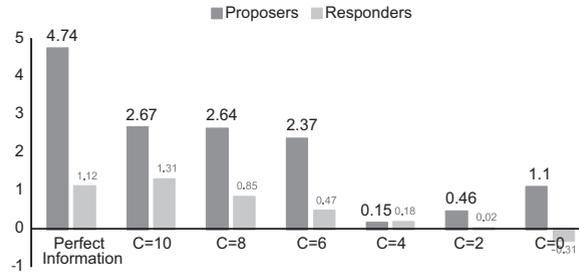


Fig. 10. Average earnings by role, SI and MH sessions.

attempts were not successful, since, as shown above, blue-note offers were accepted with a higher probability than red-note offers.

RESULT #8 (Earnings under the threat of fraud). In high-cost sessions, $C \geq 6$, the average earnings are above 28% of the maximum earnings of \$10. In low-cost sessions, $C \leq 4$, they are below 8%.

The high-cost sessions feature a monotonic decrease in subjects' earnings, from \$4 ($C=10$), to \$3.5 ($C=8$) and \$2.8 ($C=6$).³⁵ These earnings are smaller than the ones obtained under perfect information (SI), \$5.9, suggesting that the threat of fraud impairs subjects' ability to exploit gains from trade. The earnings are even lower, and slightly increasing, in the low-cost sessions.³⁶ The average match exploits more than 28% of the ME in high-cost sessions (more than 57% conditional on trading) and less than 8% in low-cost sessions (less than 37% conditional on trading).

Fig. 9 displays the average earnings as a percentage of the ME. The difference between the earnings conditional on trading and the unconditional earnings is positive by definition because rejected offers generate no earnings. The size of the difference reflects the contribution of the extensive margin (the acceptance rate) to the overall earnings. As the figure suggests, the extensive margin plays a crucial role for low costs of fraud.

Earnings can be separated by player role, as shown in Fig. 10. Proposers' average earnings are larger than \$2.4 in high-cost sessions and lower than \$1.1 in low-cost sessions. Responders' average earnings are higher than \$0.5 in high-cost sessions and lower than \$0.2 in low-cost sessions. When the moral hazard problem was very severe, $C=0$, responders made an average loss of \$0.3.

RESULT #9 (Earning shares under moral hazard). Proposers' average earnings share is constant for high-cost sessions and increasing in C for low-cost sessions. Responders' earnings share is positive, except for $C=0$.

The average fraction of earnings obtained by proposers is shown in Fig. 11. In high-cost sessions, the fraction of total earnings obtained by proposers is roughly constant and equal to the perfect-information (SI) share, being about 80%. In low-cost sessions, the responder share is increasing in C and is larger than 100% when fraud is costless (see Fig. 11).

Summary of moral hazard (MH). Results 4–8 suggest that the behavior of the subjects is largely consistent with Hypothesis 2. If fraud is costless, the threat of fraud strongly reduces the subjects' ability to exploit the gains from trade since very few offers are accepted and the size of accepted trades are small. If fraud is costly, a vast majority of offers involve genuine notes and the fraction of accepted offers, trade sizes, and earnings increase with the cost of fraud.

³⁵ With moral hazard, the maximum earnings (ME) are \$10 as in the perfect information (SI) session. A trade generates \$10 for the match if all widgets are exchanged and if $C > 0$, no money is wasted on red notes.

³⁶ The average earnings discussed below are the mean earnings of the subjects across all rounds. They do not coincide with the payout of the experiments, since the payouts are based on one round chosen at random.

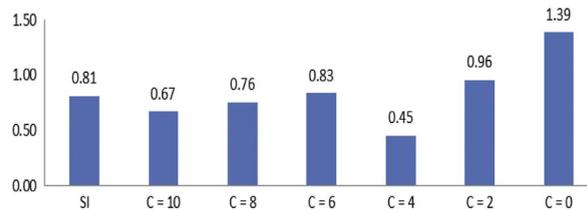


Fig. 11. Average fraction of surplus for proposers, SI and MH sessions.

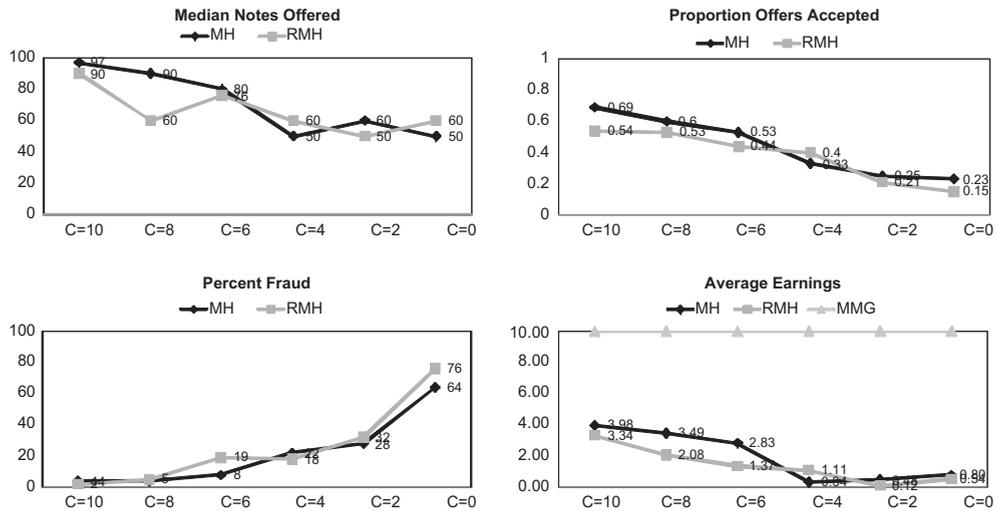


Fig. 12. MH and RMH Sessions Compared.

5.3. Testing the reverse-ordered game refinement

The theory analyzes the OTC bargaining game under the threat of fraud by adopting the reverse-ordered game refinement for signaling games with endogenous types of *In and Wright (2011)*.³⁷ In the following, we test whether the reverse-ordered game generates similar outcomes as the original bargaining game by letting subjects play the reverse-ordered game in the lab. Fig. 12 illustrates key similarities between the MH and RMH sessions that we discuss here.

RESULT #10 (Accuracy of the reverse-ordered game refinement). Outcomes of the reversed-ordered games in terms of offers, acceptability, fraud, and gains from trade, are largely consistent with those of the original game.

In accordance with Result 4, note offers are smaller than in the perfect information case, $n < 100$, and they decrease as fraud becomes cheaper. Though notes offered are statistically different with $C = 2, 4, 6, 8$ according to our nonparametric statistical analysis (see supplement appendix), they follow the same general pattern as C changes, as seen in Fig. 12. The primary exception is $C = 8$ where n is much smaller in the reverse-ordered game.

In accordance with Result 5, acceptance rates are smaller under the threat of fraud than under perfect information. Relative to the original bargaining game, acceptance rates are lower but of similar magnitude. In the RMH session, the acceptance rate picks at 54% relative to 69% in the MH sessions, and it falls down to 15% relative to 23% in the MH sessions. We also find that the acceptance rate is monotonically increasing in C in both versions of the game. Our nonparametric analysis finds no statistical difference in acceptance rates across the MH and RMH sessions, the sole exception being when $C = 10$.

Fig. 12 also shows that the fraud levels are decreasing in C and of equal magnitude in both RMH and MH sessions. When $C = 10$, the share of fraud is only 2% in the reverse-ordered, and it remains less than 5% when $C = 8$. The amount of fraud is higher, 19%, for a medium-high cost of fraud. Still, the share of fraudulent offers is less than one third for all $C > 0$, which is consistent with Result 5. When fraud is costless, $C = 0$, the fraud share jumps to 76%, which is also consistent with the theory. There is no statistically significant difference for all C except $C = 6$.

³⁷ Recall that according to this refinement, the outcome of the original bargaining game can be predicted from the subgame perfect equilibrium of a strategically equivalent game. In that game, the proposer chooses first his observed action (the offer) and then he chooses the unobserved action (whether to acquire blue or red notes).

Finally, we also find that mean earnings are increasing in C in both RMH and MH sessions. Except for $C=4$ earnings are higher when subjects play the original game. But the main message remains that subjects experience difficulties to exploit the gains from trade when the bargaining game is subject to the threat of fraud.

Summary of reverse moral hazard (RMH). The reverse-ordered OTC bargaining game generates similar, often statistically identical, subject behavior in terms of offers, acceptability, and fraud compared to the original bargaining game. Hence, it is a reasonable refinement for OTC bargaining games with hidden actions. Furthermore, the fact that we observe similar behavior across slightly different OTC bargaining games provides additional support for the robustness of our experimental results.

5.4. Further interpretation: hidden action vs adverse selection

In order to better understand the effects of informational frictions on trade, we ran two additional sessions where proposers are privately informed about the terminal value of their notes, but are not able to choose the value; i.e., Nature rather than the proposer chooses the value of the notes.³⁸ We label these new sessions $AS_{0.9}$ and $AS_{0.7}$, where AS stands for adverse selection and the index indicates the probability of blue notes, $\pi \in \{0.9, 0.7\}$, chosen by Nature. We set $\pi = 0.9$ and $\pi = 0.7$ because these values correspond to the endogenous outcomes obtained under $C=6$ and $C=2$, respectively. Some key statistics from $AS_{0.9}$ and $AS_{0.7}$ are compared with MH sessions when $C \in \{2, 6\}$ in Table 5 in order to check if subjects react differently to the uncertainty about the quality of the notes when it comes from Nature instead of other subjects' actions.

We first compare the MH session with $C=6$ with the AS session with $\pi = 0.90$. When $C=6$ the fraction of proposers who opted for blue notes is 92%, which is comparable to the fraction in the AS experiment (where the realized fraction was 88%). The median note offer and the median widget offer are slightly lower in the MH session than in the AS session, $92 > 88$ and $80 > 85$, but the acceptability of offers is slightly higher in the MH session, $53\% > 46\%$. Overall, the total number of notes that change hands is similar across the two treatments. The median offered price in the MH session, 1.25, is slightly lower than the one in the AS session, 1.29. Finally, the earnings in the MH session, \$2.84, are slightly higher than the one in the AS session, \$2.62. This comparison suggests that whether the private information problem is generated by subjects' hidden actions or by Nature is not too relevant for the outcomes of the OTC bargaining games, at least if the amount of fraud is small.

Table 5
Comparison between MH and AS^a

	$C = 6$	$AS_{0.9}$	$C = 2$	$AS_{0.7}$
Blue Notes in %	92	88	72	79
Notes Offered	80	85	60	60
Widgets Requested	65	67	50	50
Price offered	1.25	1.29	1.33	1.29
Acceptance rates in %	53	46	25	39
Earnings	2.84	2.62	0.5	1.65

^a All entries are medians except for the acceptance rate and earnings (average in \$).

Next, we compare the MH session when $C=2$ that has an endogenous fraction of blue notes of 72% with AS session when $\pi = 70\%$ (in the experiment the realized π is 79%). In each case, the median number of notes offered is 60 and the median number of widgets requested is 50. So the intensive margin of the trade is identical. However, the acceptance rate of offers is significantly lower in the MH session, 25%, compared to 39% in the AS session. The threat of fraud, therefore, appears to have a larger effect on overall trade, since responders tend to "trust" Nature more than other subjects. As a result, the average earnings are much smaller in the MH session, \$0.5, compared to the AS session, \$1.65. Some of this difference is due to the fact that about 30% of subjects bought red notes at the cost of \$2, which reduces the average gain by about \$0.6. The rest of the difference comes from the lower acceptance rate.

6. Conclusion

We have presented a simple theory of bargaining games in decentralized markets under perfect and private information. In these two-dimensional bargaining games, agents trade a commodity (called 'widget') that they value differently – hence the presence of gains from trade – for a medium of exchange (called 'note') that has the same value for all market participants. In order to assess the effects of informational frictions regarding the common value of the medium of exchange, we compared a benchmark case where agents are symmetrically informed (SI) about the terminal value of notes with six conditions in which note-holders can take hidden actions (MH) to affect the terminal value of the notes. After having

³⁸ In all these sessions, the subjects had access to an on-screen calculator to help them compute payoffs for different hypothetical offers.

derived a set of theoretical predictions for this environment under different information structures, we took the model to a laboratory setting to test its predictions.

The main lessons of this exercise are as follows. First, the experimental subjects' behavior in the bargaining game under perfect information is largely consistent with the theory: Most offers are individually rational and close to the Pareto frontier, and a large fraction of offers are accepted. Second, the experimental data is also consistent with the predictions of the model under the threat of fraud with noteworthy differences. We found that the possibility of fraud affects trade on both the intensive and extensive margins: Subjects trade less often, and when offers are accepted they trade smaller quantities. As a result, the threat of fraud strongly reduces the ability of subjects to achieve the gains from trade. A policy implication of this result is that measures to improve the recognizability of means of payment—such as the periodic redesign of currencies by central banks—have real effects by increasing the volume of trade and are welfare improving. While the theory predicts that no fraud should occur in equilibrium (provided that fraud is costly), we observed some fraud in the experiments. However, the amount of fraud was always small. Because the volume of fraud is negatively correlated with the cost of fraud, it provides an indicator of the recognizability of the means of payment. When fraud was costless, the volume of trade was very low but positive, in contrast to the complete shut-down predicted by theory. So, even though trade is affected by the threat of fraud, it is also resilient. Third, behavior in the reverse-ordered game closely matches the behavior in the original ordered setting, suggesting that the reverse-ordered game is a valuable refinement for the study of OTC bargaining games under hidden actions.

Our model is simple and tractable and can be extended in many ways. For instance, it can be used to study how incentives to acquire information matter for asset and market liquidity. One can also use our model to investigate other dimensions of collateralized trades, such as haircuts, and how these dimensions are affected by various informational frictions. We leave these different questions for future research.

Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version at <http://dx.doi.org/10.1016/j.jedc.2016.11.003>.

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