Limelight on Dark Markets: Theory and Experimental Evidence on Liquidity and Information*

Aleksander Berentsen
University of Basel and Federal Reserve Bank of St.Louis

Michael McBride
University of California, Irvine

Guillaume Rocheteau
University of California, Irvine

February 24, 2014

Abstract

This paper investigates how informational frictions affect asset liquidity in OTC markets both 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. The asset's role as a medium of exchange can be affected by its lack of "recognizability." The benchmark is a two-dimensional OTC bargaining game with complete information. In the adverse selection experiments, some subjects have private information about the asset's terminal value. In the hidden action experiment, some subjects can produce fraudulent assets at some cost. Finally, we allow subjects to choose their holdings of the liquid asset, where the asset can vary in terms of its rate of return and recognizability property.

JEL Classification: G12, G14, E42, D82, D83
Keywords: liquidity, money, information, experiments

*Berentsen (aleksander.berentsen@unibas.ch): Department of Economics, University of Basel, Switzerland. McBride (mcbride@uci.edu): Department of Economics, University of California-Irvine, USA. Rocheteau (grochete@uci.edu): Department of Economics, University of California-Irvine, USA. For comments on earlier versions of this paper we thank participants of the Summer Workshop on Money, Banking, Payments and Finance at the Federal Reserve Bank in Chicago and seminar participants at the University of California, Santa Barbara. This research benefited from the financial support of the Foundation Banque de France. McBride also acknowledges financial support from Air Force Office of Scientific Research Award No. FA9550-10-1-0569 and Army Research Office Award No. W911NF-11-1-0332. The usual disclaimer applies.

"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 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)

1 Introduction

Since at least Jevons (1875) it is 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. Assets that lack recognizability might not be universally accepted in payment for goods and services or as collateral to secure loans.[1] Such private information problems 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. These markets where fixed income securities, bilateral loans, and credit derivatives are traded play a pivotal role for the financing of the economy. A case in point is the market for bilateral repurchase agreements (repos)—a market that allows banks to finance securities through short-term collateralized loans. Prior to the 2008, 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.

Despite their crucial role, OTC markets are *dark markets*—a term coined by Duffie (2012)—for which relatively little information is made publicly available.[2] Little is known about the information held by market participants at the time of a trade and how this information affects trade outcomes. On the theory side, there

[1] This idea is captured by Gresham's law according to which in the presence of a private information problem only the lowest quality of a commodity money will circulate widely—a manifestation of a standard adverse selection problem. For a quick overview, see Dutu, Nosal, and Rocheteau (2005). Recently, Gorton and Metrick (2009) emphasized a closely related notion, "information-insensitiveness," that applies to assets or securities serving as collateral. An asset is information insensitive if traders have no incentive to acquire private information about its future cash flows. Gorton and Metrick argue that liquidity crises occur when securities that are part of the liquidity of the economy suddenly become information sensitive.

[2] For a description of the transparency of different OTC markets, see Duffie (2012, Section 1.2.)

is a growing literature describing the functioning of OTC markets with pairwise meetings and bargaining—pioneered by Shi (1995) and Trejos and Wright (1995) in monetary economics, and Duffie, Gârleanu, and Pedersen (2005) in financial economics—but private information problems are usually assumed away. In reality, however, informational asymmetries are prevalent making the OTC market game complex. In Duffie's (2012, p.2) words:

> "*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.*"

When the private information frictions are taken into account, one has to deal with the difficult task of selecting an equilibrium by refining out-of-equilibrium beliefs.[3] There are many refinements that generate very different outcomes and theory provides little guidance which ones to choose. In order to overcome some of these challenges, we study how informational frictions affect trading in OTC markets in a laboratory setting.

The experimental approach allows us to generate our own observations on how agents trade in markets with bilateral meetings and bargaining under private information and to control market participants' incentives and information. We investigate how different forms of informational asymmetries (both in terms of adverse selection and moral hazard) affect an asset's resalability, its role as a medium of exchange, and allocative efficiency. Furthermore, we ask if private information can generate endogenous trading frictions in OTC markets; i.e., whether private information reduces the liquidity of an asset and under which conditions it lead to market breakdowns. We will also investigate whether mechanisms emerge endogenously to mitigate the informational asymmetries, such as asset retention.

The environment we use to represent an OTC market is directly inspired from the one used in monetary and financial economics (Shi, 1995; Trejos and Wright, 1995; Duffie, Gârleanu, and Pedersen, 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. The transaction

[3] Models of OTC markets with private information include Rocheteau (2011), Li, Rocheteau, and Weill (2012), Camargo and Lester (2013), and Guerrieri and Shimer (2012).

involves individuals buying commodities—called widgets—that have different private values with assets—called notes—that have a common value but that can be subject to a private information problem. The asset plays the role of a medium of exchange, but this role can be affected by its lack of "recognizability" or the uncertainty about the future cash flows of the asset. 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 it is also key to allow signaling to take place under private information (e.g., Nosal and Wallace, 2007).

The OTC bargaining game is a two-dimensional ultimatum game with a proposer and a responder. 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.[4] 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 to the responder, where the offer has two dimensions, a number of widgets for a number of notes. In order to keep the problem as simple as possible for the subjects of the experiments, all payoffs are linear.

In our benchmark experiment, the terminal value of a note is \$0.1 and it is common knowledge. The endowment of 100 notes implies a payment capacity of \$10. A widget is worth \$0.1 to a responder but \$0.2 to a proposer. With this informational setting, we find that the outcomes of the experiments 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. On average a proposer offers 87 notes for 74 widgets. So only 13% of all notes stay idle, and the median notes offered is 100. The average price of a widget, defined as the number of notes exchange for a widget, across accepted offers was 1.21 notes, above the unit price predicted by theory, whereas the average price across rejected offers as 1.1. This outcome captures the standard fairness considerations found in the experimental literature on ultimatum games.[5]

[4] The property according to which an asset or commodity has a common value to all traders for it to play a role as a medium of exchange has been emphasized by Engineer and Shi (1998, 2001) and Berentsen and Rocheteau (2003).

[5] The exchange of a widget generates a match surplus 0.1\$. An average price of accepted offers of 1.21 means that the

We study informational asymmetries in this setting by introducing two types of notes—blue and red ones—and by assuming that responders cannot observe the color of the notes offered by the proposers. The terminal value of a blue note is \$0.1, as in our benchmark experiment, while the terminal value of a red note is zero—we think of the red note as a useless counterfeit. Across sessions we vary the probability that a proposer is endowed with blue notes from 50%, to 70%, and 90%.

When using the theory to interpret the results from the experiments we pay special attention to two perfect Bayesian equilibria of the OTC bargaining game: the best pooling equilibrium from the viewpoint of the proposer and the equilibrium obtained under the intuitive criterion of Cho and Kreps (1987). Under the pooling equilibrium, all offers are accepted at a pooling price that exactly compensates the responder from the possibility of the occurrence of red notes. Moreover, proposers spend all their notes but can only acquire a fraction of the widgets of the proposers. In contrast, under the intuitive criterion a proposer with blue notes can break a pooling equilibrium by retaining a fraction of his/her notes in exchange for a better price. Since red notes are valueless, a separating equilibrium cannot exist and the only equilibrium outcome is such that all trades shut down—an extreme consequence of the adverse selection problem. In summary, according to the pooling equilibrium the private information problem should manifest itself by a lower price of the notes and a lower number of widgets traded (the intensive margin) in pairwise meetings but the number of trades (the extensive margin) should be unaffected, whereas according to the intuitive criterion the private information problem should lead to all offers being rejected.

The outcomes of our experiments share features of both equilibria: trade is reduced on both the intensive and the extensive margin and prices are higher compared to the benchmark. The price of widgets across accepted offers decreases from 1.5 to 1.42 and 1.34 as the probability of blue notes increases. We ran the same experiments with *symmetrically uninformed* subjects and found prices varying from 2.4, to 1.59, and 1.53.[6] Prices when subjects are asymmetrically informed are lower than when they are symmetrically uninformed. Our interpretation is that the proposers attempted to signal good quality notes by offering few notes for widgets. Furthermore, the fraction of accepted offers fell: the acceptance rates were 30%, 39%, and 47%

responder requires about 21% of the match surplus.

[6] As for the benchmark experiment, the exchange of a widget generates a suplus of 0.1\$. A price of 2.4 means that the responder requires a share of 20% of the total surplus, since the expected value of a note is 0.05\$. Along the same line, a price of 1.59 means that the responder requires 11.3% of the surplus, and a price of 1.53 means that the responder requires 37.7% of the surplus.

for the three sessions described above and 73% when the value of notes were certain. However, we didn't find clear evidence that the signaling mechanism implied by the intuitive criterion could explain the large fraction of rejected offers. In particular, we obtained only slightly higher acceptance rates when subjects were symmetrically uninformed, namely 35%, 39%, and 58%. Furthermore, proposers with blue notes offered more notes than proposers with red notes in contrast with an asset retention mechanism. Altogether these results suggest that the uncertainly about the value of the medium of exchange matters for its liquidity regardless of whether information is symmetric or asymmetric. We view these results as consistent with the demand for absolute safety emphasized by Krishnamurty and Vissing-Jorgensen (2012) to explain the liquidity and convenience yield of Treasury debt and highly-rated corporate bonds. The results also illustrate how informational frictions generate search-like frictions despite the fact that the matching technology is frictionless.

In all previous experiments, the frequency of occurrence of low-value notes was exogenous, chosen by Nature. We conjectured that this feature might explain why the outcome of the treatment where agents are asymmetrically informed is similar to the one where they are symmetrically informed. In reality the existence of low-quality media of exchange or collateral often results from deliberate actions by some individuals, e.g., con artists printing counterfeits.[7] In order to capture this idea we ran three experiments where the proposer had the possibility to produce fraudulent assets, i.e., red notes, at some cost. The proposer was endowed with $10 and had the choice to buy either 100 blue notes for 10$, or to buy 100 red notes for some amount of dollars that we interpret as the cost of fraud. Across sessions we vary this cost of fraud from $0, to $2 and $6.

If the cost of fraud is strictly positive, the best (perfect Bayesian) equilibrium from the viewpoint of the proposer predicts that there is no fraud. The reason is that the proposer understands that he/she cannot benefit from fraud when it is anticipated. Moreover, the proposer can signal his/her good behavior by retaining a sufficiently large number of notes so that fraud is not worthwhile. If the cost of fraud is zero, theory predicts that there can be fraud, but no offer is accepted. In accordance with the empirical evidence,

[7] Classical examples of fraud in monetary and financial affairs include the clipping of coins in ancient Rome and medieval Europe, and the counterfeiting of banknotes during the first half of the 19^{th} century in the United States (see, e.g., Mihm, 2007). According to Gorton and Metrick (2010), prior to the 2008 financial crisis large volumes of repurchase agreements backed by securitized bonds were traded daily without extensive due diligence. These securitized bonds were subject to moral hazard problems, fraudulent practices, and lax incentives (Keys, Mukherjee, Seru, and Vig, 2010; Barnett, 2012).

we found some amount of fraud in all experiments.[8] However, fraud decreased monotonically with the cost of fraud: the fraction of proposer that acquired blue notes was 34% when the cost of fraud is \$0, 63% when the cost of fraud is \$2, and 92% when the cost of fraud is \$6. So a high cost of fraud eliminates counterfeit notes almost entirely. Surprisingly, even when fraud is costless, some subjects do hold blue notes and some offers are accepted. This illustrates the difficulty of generating a complete market freeze. Proposers with blue notes offered fewer notes and asked for lower prices than proposers with red notes, which could be interpreted as an attempt to signal their value. However, these signaling attempts were unsuccessful, since accepted and rejected offers contained roughly the same number of blue notes.

The acceptance rates in treatment with hidden actions were low, namely 27%, 24%, and 46%.[9] This finding is consistent with the theory that predicts that offers should be rejected with positive probability in order to discipline the proposers. The failure to trade is even stronger when the cost of fraud decreases. Under a \$2 cost of fraud, the proposer acquired valuable notes in 63% of the rounds, but only 24% of their offers were accepted. In the adverse selection case, the probability of red notes had to be equal to 50% in order to obtain such low acceptance rates. In summary, whether a private information problem is exogenous to the subjects or one that results from hidden actions matters for the liquidity of an asset: the latter exacerbates the illiquidity of the asset.

So far the payment capacity, or holdings of liquid assets, of the proposers was taken as given: each proposer had exactly 100 notes. In our last four experiments we check how our results are affected when proposers are able to choose their holdings of liquid assets (notes). This extension brings the model even closer to modern monetary theory as represented by the Lagos-Wright model. In the first three experiments, we let proposers choose the amount of notes (up to 100) they carry in a match. The purchase price of a note varies across sessions from \$0.1, \$0.11 to \$0.15 allowing us to change the rate of return of the notes (i.e., their holding cost) since the terminal value of a note is still \$0.1. In each of the three cases, proposers were endowed with \$10, \$11, and \$15 so that they could acquire 100 notes in maximum. The first case corresponds to the Friedman rule where there is no holding cost of money. Under the Friedman rule, proposers acquired

[8] The value of counterfeit currency in 2005 was about 1 dollar for every \$12,400 in circulation. 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.

[9] Interestingly, in one treatment the proposer chose valuable notes in 92% of all rounds, which is comparable to the exogenous 90% of one of our adverse selection session. The acceptance rate under moral hazard is 46%, while the acceptance rate under adverse selection is 47%.

in average 82 notes and hence did not maximize their payment capacity. This observation goes against the theory that predicts that subjects should satiate their liquidity needs under the Friedman rule. In the other two cases, they acquired 61 and 62 notes. The fact that proposers choose to invest in blue notes even when their purchase price is greater than their resale price is in accordance with a rate-of-return dominance pattern and consistent with search-theoretic models where the cost of holding money is one of the key modelling choices. The investment in notes is lower than what the theory predicts, but one can rationalize proposers' liquidity choices by the fact that a significant fraction of offers are rejected (about 40%) and proposers are only able to capture a fraction of the match surplus (about 80%). Both factors reduce the demand for liquidity.

In our last experiment, we investigate how informational asymmetries about the value of an asset affects subjects' liquidity choices. We give the choice to the proposers between acquiring blue notes that are costly to hold or orange notes that have a higher return but that are indistinguishable from red notes. In accordance with the theory we find that some subjects hold blue notes despite the fact that they are dominated in their rate of return. However, only one fourth of the subjects hold rate-of-return-dominated notes while a large fraction of subjects choose red notes. This observation can be explained by the fact that some responders are willing to accept notes of unknown quality. It seems that over time subjects are learning not to accept such notes but such learning is slow.

1.1 Related literature

The search-theoretic literature on adverse selection in decentralized asset markets with pairwise meetings includes Cuadras-Morato (1994) on the emergence of a commodity money, Velde, Weber, and Wright (1999), and Burdett, Trejos, and Wright (2001) on Gresham's law, and Hopenhayn and Werner (1996) on the liquidity structure of asset returns. These papers restrict asset holdings to $\{0,1\}$. 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. Banerjee and Maskin (1996) do not restrict asset holdings, but they study the emergence of commodity monies in an environment with Walrasian trading posts. The assumption of price-taking agents rules out the strategic considerations in the pairwise meetings that are the focus of this paper. In Lester, Postlewaite, and Wright (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. Li, Rocheteau, and Weill (2012) consider a model of an OTC market where assets are subject to costly fraudulent practices and solve the bargaining game under incomplete information.

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. They find that fiat money can circulate it has the lowest storage cost, and they do not find support for rate-of-return dominance. Our paper emphasizes a different property of monetary assets, their recognizability. Duffy and Puzzello (2011) is the first attempt to bring the Lagos-Wright 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, Kim, and Moser (1996) where players have different information about each other's payoffs and Miltzkewitz and Nagel (1993) where one subject is uninformed about the size of the gains from trade. Similarly, Forsythe, Kennan, and Sopher (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, Section 4.3).

Closer to what we do, Forsythe, Lundholm, Rietz (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. The asset that is commonly valued across subjects has a role as a medium of exchange but is subject to a private information problem. Moreover, we let the uninformed party make an offer, which opens up the possibility for signaling. Finally, our adverse selection treatment paper is related to the signaling model of corporate finance. Cadsby, Frank, and Maksimovic (1990) test the pecking order theory where firms can finance projects of heterogenous qualities by issuing shares to investors. They find that the results accord with the theory.

2 OTC bargaining game under symmetric information

Our experiment aims to describe an OTC market where individuals are matched bilaterally and at random and bargain over the terms of trade.[10] 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. As shown in the monetary literature, under symmetric information this bargaining protocol maximizes the liquidity value of the asset.[11]

The two players in the bargaining game are called *Proposer* and *Responder*.[12] 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 participants.[13] 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.[14] 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

[10] In reality this OTC market can be a market for financial assets, as described in Duffie, Garleanu, and Pedersen (2005), or a decentralized market for goods and services, as in Shi (1995), Trejos and Wright (1995).

[11] For a review of the relevant search-theoretic literature on monetary exchange, see Rupert, Schindler, Schevchenko, and Wright (2000).

[12] 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.

[13] 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 those 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 constrast to Lucas trees they are valued equally by all agents.

[14] For a literature review of search-theoretic models of dual-currency economies see Craig and Waller (2000).

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.[15] The objective of this paper is to see how private information about the quality of the medium of exchange affects the frequency of trade (the extensive margin), the size of the trades (the intensive margin), and the division of the match surplus.

2.1 Bargaining under complete information

As a benchmark we consider the case where notes are homogenous and the proposer and the responder have complete information about the terminal value of notes; i.e., notes are perfectly recognizable. The trading mechanism is such that the proposer (the note holder) makes a take-it-or-leave-if 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.[16]

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).[17] For proposers and responders alike 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 $U_P = 2\omega + 100 - n$. Following the same trade the responder keeps $100 - \omega$ widgets and receives n notes. Accordingly, his payoff (in terms of the numéraire) 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

[15] 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 equals to one, let say, because of liquidity needs or hedging reasons.

[16] The fact that both money (notes) and goods (widgets) are divisible is in contrast to Shi (1995) and Trejos and Wright (1995) where money is in $\{0, 1\}$ and to Duffie, Garleanu, and Pedersen (2005) where the asset is in $\{0, 1\}$. In this regard our model is closer to the new generation of monetary models of Shi (1997) and Lagos and Wright (2005) and the model of OTC financial market of Lagos and Rocheteau (2009). In the experiments, the players have to choose integers in $\{0, ..., 100\}$.

[17] For a critical discussion of this assumption, see Rabin (2000).

to the data.

Individual rationality First, we check 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

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

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

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

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

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

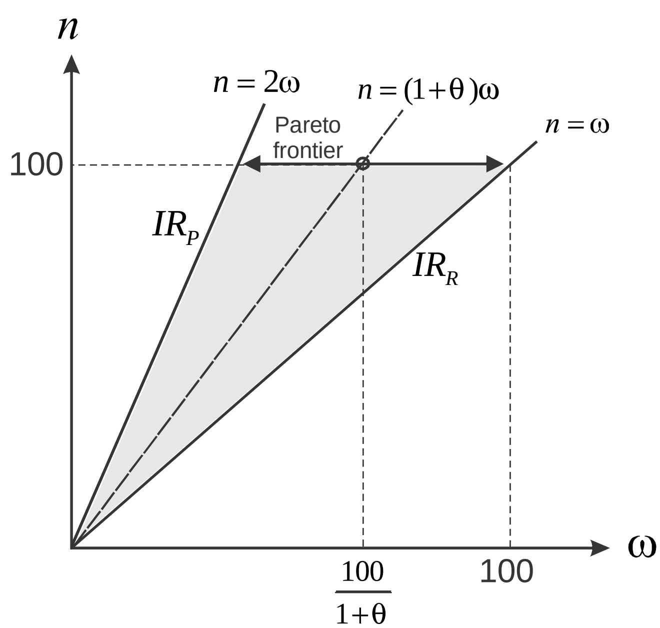


Figure 1: Bargaining game under complete information

The set S is depicted in Figure 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.[18] The Pareto frontier associated with this bargaining problem solves

$$\mathcal{S}_P = \max_{\omega,n} (2\omega - n) \quad \text{s.t. } n - \omega = \mathcal{S}_R, \tag{3}$$

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 proposer should use his full payment capacity (the 100 notes) to maximize gains from trade and the transfer of widgets will determine the distribution of those gains from trade. The equation for the Pareto frontier in the utility space is $\mathcal{S}_P + 2\mathcal{S}_R = 100$. See top quadrant of Figure 2. So the proposer obtains a surplus equal at most to 100 while the maximum surplus of the responder is 50.[19] The set of Pareto-efficient offers is represented in the bottom quadrant of Figure 2. Note that any allocation on the Pareto frontier is the outcome of a Nash equilibrium.

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, $\mathcal{S}_P \equiv 2\omega - n \geq 0$, where $\theta \in [0, 1]$. The *motivation function* of the responder becomes

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

As a result for a responder to benefit from a trade, his own surplus, $\mathcal{S}_R \equiv n - \omega$, must be larger than $\theta/(1-\theta)$ the surplus of the proposer.

Behavioral Assumption. Responders only accept offers that satisfy $\mathcal{S}_R \geq \frac{\theta}{1-\theta}\mathcal{S}_P$.

[18] This property of the allocation corresponds to the pairwise core requirement in the mechanism design literature in monetary theory. See, e.g., Hu, Kennan, and Wallace (2009).

[19] 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 $\mathcal{S}_R + \mathcal{S}_R = 100$ and all Pareto-efficient trades would be such that $\omega = 100$.

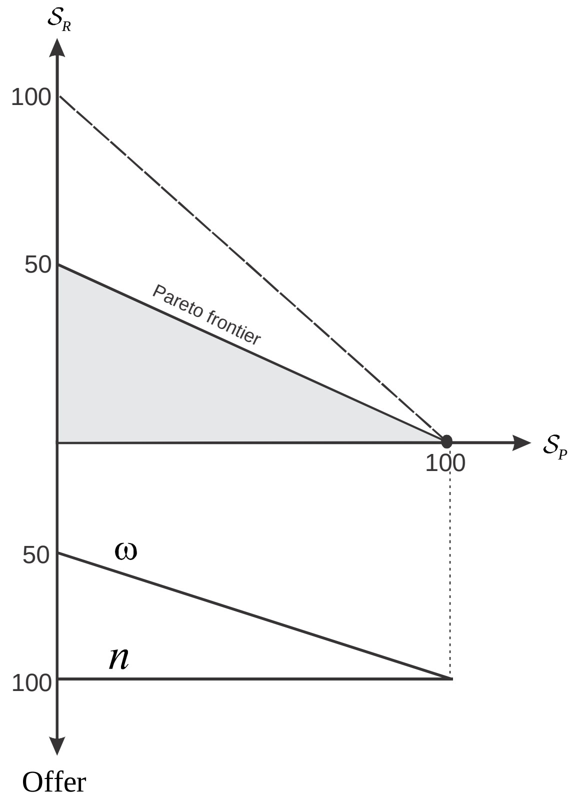


Figure 2: Pareto frontier of the bargaining set

We directly incorporate this notion of fairness for three reasons.[20] First, our formulation is equivalent to Kalai's (1977) proportional bargaining solution that 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.[21] 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

[20] 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, Rocheteau, and Waller, 2007) and the experimental literature. Two well-known ways to incorporate fairness in bargaining models are Bolten and Ockenfels (2000) and 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).

[21] See Roth (1996) 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. Our formulation accounts for fairness alone for simplicity.

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. In reality it seems reasonable to think that there is a distribution of θs across individual and each θ is private information.

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 responder solves the following problem:

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

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 Figure 1. The proposer's surplus is equal to $(1-\theta) \times 100$ while the responder surplus is $\theta \times 100$. As θ varies on $[0, 1]$ the outcome describes the whole Pareto frontier. The data from the experiments will allow us to estimate θ.

2.2 Bargaining under symmetric but imperfect information

We introduce imperfect information in the OTC bargaining game by assuming that the terminal value of the notes that the proposer is endowed with is random. With probability π, the proposer is endowed with notes that pay off one unit of numéraire each, and with complement probability $1-\pi$, the proposer is endowed with low-quality notes that pay off 0 unit of the numéraire good.[22] Throughout the paper we refer to the high-quality notes as *blue* notes and the low-quality notes as *red* notes. We use the same neutral terminology in the experiments.

In the absence of fairness considerations the set of individual rational trades for a proposer and a responder become

$$P \equiv \left\{ (\omega, n) \in [0, 100]^2 : 2\omega - \pi n \geq 0 \right\} \tag{6}$$

$$R \equiv \left\{ (\omega, n) \in [0, 100]^2 : \pi n - \omega \geq 0 \right\}. \tag{7}$$

[22] Lagos (2010) considers a related model where Lucas trees that pay a stochastic dividend are used as means of payment in decentralized trades. Such a model is used to account for the equity premium puzzle. In Nosal and Rocheteau (2011, Ch.7) the value of money is random due to stochastic inflation.

The effective payment capacity of the responder has been reduced since $\pi n \in [0, 100\pi]$. The Pareto efficient trades are such that the proposer offers all his notes ($n = 100$), as before, but now he can only ask for $\omega \in [50\pi, 100\pi]$ widgets.

Finally we turn to the outcome of the SPE when the responder values fairness. As before, the responder accepts an offer if it satisfies the fairness requirement, $\mathbb{E}S_R \geq \frac{\theta}{1-\theta}\mathbb{E}S_P$, where $\mathbb{E}S_R = \pi n - \omega$ and $\mathbb{E}S_P = 2\omega - \pi n$. The fairness constraint at equality implies $\pi n = (1+\theta)\omega$. The solution to the proposer's problem is $n = 100$ and $\omega = 100\pi/(1-\theta)$. See Figure 3.[23]

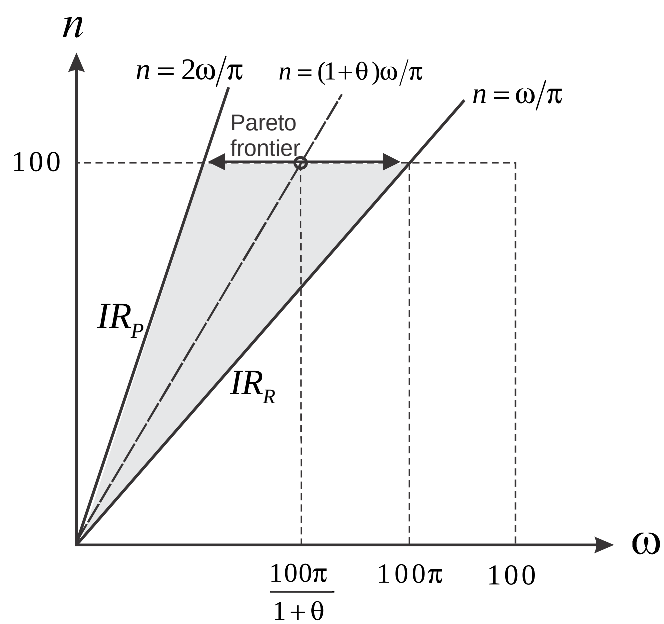


Figure 3: Bargaining game under symmetric but imperfect information

The Symmetric Informed (SI) and Symmetric Uninformed (SU) settings described so far provide benchmarks from which to compare behavior in the other settings. We will want to confirm that the subjects' behavior conforms to basic rationality principles and is consistent with behavior in simpler ultimatum games.

[23]The assumption of risk neutrality is important for this result. Suppose instead that agents are risk averse and that their preferences can be represented by a strictly concave utility function u. The problem of the Proposer becomes

$$\max_{n,\omega} \{\pi u\,(100 - n + \omega) + (1-\pi)u(\omega)\} \text{ s.t. } \pi u\,(100 - \omega + n) + (1-\pi)u(100-\omega) \geq u(\omega).$$

Suppose $u(c) = (c+b)^{1-a}/(1-a) - b^{1-a}/(1-a)$ and $\pi = 0.5$. For low coefficients of risk aversion it is still the case that the optimal offer of the proposer is such that $n = 100$. For instance, if $a = 0.5$ and $b = 0$, then $n = 100$ and $\omega = 44$. For higher coefficients of risk aversion it can be that $n < 100$. Suppose $a = 2$ and $b = 1$, then $n = 83$ and $\omega = 27$.

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

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

3 Bargaining under adverse selection

We now introduce informational asymmetries in the OTC bargaining game. As before the terminal value of the notes that the proposer is endowed with is random: they pay off one with probability, π, and 0 with probability, $1 - \pi$.[24] The key difference with respect to the previous section is that the proposer has private information regarding the terminal value of the notes. This assumption captures the fact that for some securities the holder of the asset receives private information about its future cash flows, what Plantin (2009) calls "learning by holding".[25]

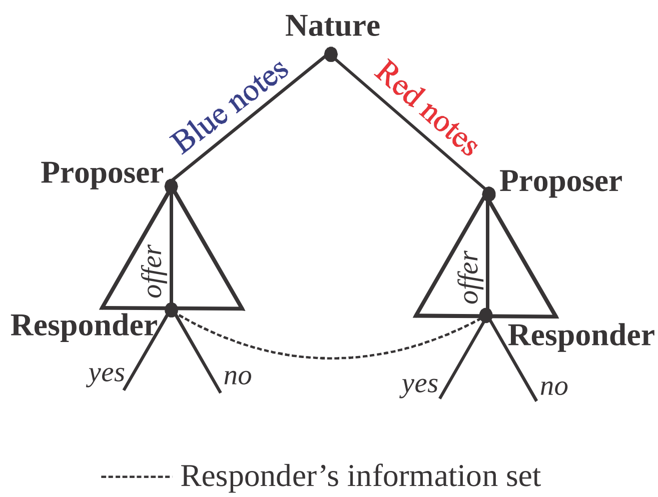


Figure 4: Tree of the bargaining game under adverse selection

The bargaining game has the structure of a signaling game: the informed party, the proposer, chooses the offer that the uninformed party can accept or reject. See game tree in Figure 4. It admits a large number

[24] The case where red notes have a positive terminal value, $\rho > 0$, is studied in the Appendix. Here we think of a situation where red notes are pure counterfeits. For a similar assumption, see Nosal and Wallace (2007).

[25] This assumption is relevant for assets that are not traded publicly, such as securitized pools of loans. It can also account for the circulation of coins of different qualities in medieval Europe or the circulation of genuine and fake notes in modern economies. For instance, Velde, Weber and Wright (1999) explain Gresham's law with an adverse selection problem in a search environment with a fixed supply of indivisible coins of different qualities.

of Perfect Bayesian Equilibria (PBE) where strategies are optimal given beliefs, and beliefs are updated according to Bayes's rule whenever possible. For instance, any offer (ω, n) that satisfies $2\omega - n \geq 0$ and $\pi n - (1+\theta)\omega \geq 0$ is the outcome of a PBE. Any such equilibrium has the property that the Proposer makes an offer that is accepted by the Responder and any deviating offer is rejected. The equilibrium is sequentially rational because any deviating offer is attributed to someone holding red, valueless notes.[26] Under our assumption that red notes are valueless we can rule out pure separating equilibria with $\omega > 0$ since responders would reject offers made by Proposers with red notes.

The predictions of the theory can be tightened by adopting standard refinements of PBE.[27] We will consider the best pooling equilibrium from the view point of a proposer with blue notes. This equilibrium is consistent with the notion of undefeated equilibrium of Mailath, Okuno-Fujiwara and Postlewaite (1993).[28] The best pooling offer solves

$$\max_{\omega,n} (2\omega - n) \quad \text{s.t.} \quad \pi n - (1+\theta)\omega \geq 0.$$

The solution is $n = 100$ and $\omega = 100\pi/(1+\theta)$. Notice that the surplus of proposer with blue notes is

$$\mathcal{S}_P^b = 2 \times \frac{100\pi}{1+\theta} - 100 = \left(\frac{2\pi - 1 - \theta}{1+\theta}\right) 100.$$

This surplus is non-negative if and only if $\pi \geq (1+\theta)/2$. If $\pi < (1+\theta)/2$, then there are no pooling equilibria that would make both types of proposers better off and there is no separating equilibrium that would make a proposer with blue notes better off. This condition illustrates how fairness considerations can affect the existence of an active equilibrium. As responders demand more fairness, θ increases, an active equilibrium is less likely to exist.

The offer corresponding to the best pooling equilibrium from the viewpoint of a Proposer with blue notes is marked by a circle in Figure 5. The curve labelled IR_R^1 is the set of offers that yield zero expected surplus to a responder who believes that the notes offered are blue with probability 1 and who doesn't value fairness, $\theta = 0$. The curve labelled IR_R^π is the set of offers that yield zero expected surplus to a responder who believes that the notes offered are blue with probability π and who doesn't value fairness, $\theta = 0$. Finally, the curve labelled IR_P^H is the set of offers that yield zero expected surplus to a proposer holding

[26] One can also construct equilibria where offers are partially accepted or semi-pooling equilibria.
[27] We show in the appendix that under the intuitive criterion of Cho and Kreps (1987) the only outcome is no trade.
[28] For a more detailed review of refinements of sequential equilibria for OTC bargaining games under adverse selection see the supplementary appendices in Rocheteau (2009).

blue notes. The grey area is the set of offers that are individually rational if responders do not update their prior beliefs in the absence of fairness consideration. Not too surprisingly this set is smaller than the one in the game with complete information. The offer that maximizes the utility of the proposers among all pooling equilibria is located on the Pareto frontier of the game with complete information. Recall that in the complete information case, the best offer when the responder values fairness is $(\omega, n) = \left(\frac{100}{1+\theta}, 100\right)$. Thus, the surplus of the proposer with blue notes is smaller with adverse selection.

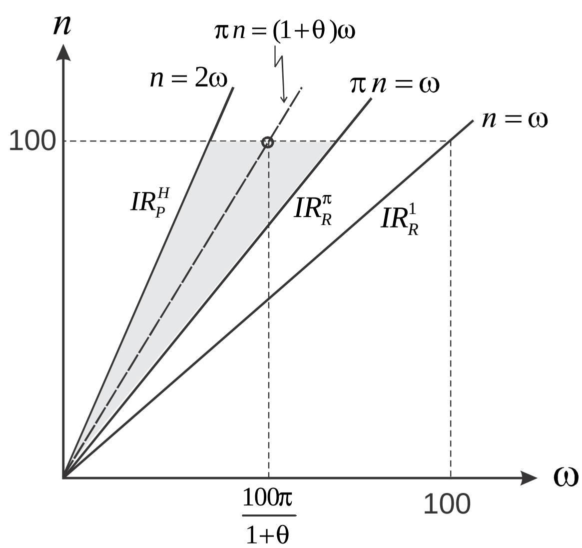


Figure 5: Adverse selection and pooling equilibria

In summary, the theory for the adverse selection treatment identifies multiple equilibria. Any outcome, (ω, n), such that $2\omega - n \geq 0$ and $\pi n - (1+\theta)\omega \geq 0$ can be part of an equilibrium. We will check whether these two incentive constraints hold for some $\theta \in [0, 1]$. We will also check whether individual rationality holds under the most optimistic beliefs, $2\omega - n \geq 0$ and $n - (1+\theta)\omega \geq 0$. Among all equilibria, we will pay a particular attention to the best pooling equilibrium from the viewpoint of the proposer with blue notes. In this case the number of notes offered should be maximum and equal to 100.

Hypothesis 2 *(Adverse Selection)* Trades satisfy one of the following patterns:

1. (Perfect Bayesian Equilibria) For any $\pi \geq (1+\theta)/2$, the proposer offers $n \in [0, 100]$ notes and receives between $n/2$ and $\pi n/(1+\theta)$ widgets, and the offer is accepted.

2. (Undefeated Equilibrium) The proposer offers 100 notes and asks for $\omega = 100\pi/(1+\theta)$ widgets.

4 Bargaining under the threat of fraud

We now consider a game where the quality of the notes is chosen by the proposer. This model captures a situation where a con-artist produces counterfeit notes or where a financial institution originates and securitizes bad loans that are sold afterwards to other investors.[29] 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. 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.[30] 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 or not to acquire blue or red notes. The advantage of this methodology is that following an offer, there is a proper subgame that can be easily analyzed.[31]

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:

$$-100 + p\left(2\omega + 100 - n\right) + (1-p)100 \left\{ \begin{array}{c} > \\ = \\ < \end{array} \right. -C + p2\omega \Rightarrow \eta \left\{ \begin{array}{c} = 1 \\ \in [0,1] \\ = 0 \end{array} \right. \tag{8}$$

The left side of (8) is the proposer's expected payoff if he chooses to acquire blue notes: he pays 100 to purchase 100 blue 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 side of (8) is the expected payoff of the proposer if he acquires red notes: the cost

[29] For examples of fraud on media of exchange, see Li, Rocheteau, and Weill (2012).

[30] 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 buyer, the agent making the offer.

[31] 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.

of red notes is C, and with probability p the offer is accepted, in which case he receives ω widgets. The best-response function (8) can be rewritten as

$$pn \begin{cases} < \\ = \\ > \end{cases} C \Rightarrow \eta \begin{cases} = 1 \\ \in [0,1] \\ = 0 \end{cases} \tag{9}$$

The condition, $pn \leq C$, for the accumulation of blue notes can be interpreted as a liquidity or resalability constraint.[32] 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 best-response of the responder is

$$\eta n - \omega \begin{cases} > \\ = \\ < \end{cases} \frac{\theta}{1-\theta}(2\omega - \eta n) \Rightarrow p \begin{cases} = 1 \\ \in [0,1] \\ = 0 \end{cases} \tag{10}$$

since ηn is the expected value of the notes and ω is the cost of giving up ω widgets. According to our behavioral assumption, a responder accepts an offer if his expected surplus is at least equal to $\frac{\theta}{1-\theta}$ the expected surplus of the responder. This best response can be rexpressed as

$$\eta n \begin{cases} > \\ = \\ < \end{cases} (1+\theta)\omega \Rightarrow p \begin{cases} = 1 \\ \in [0,1] \\ = 0 \end{cases} \tag{11}$$

Based on the best-response functions (9) and (10) the Nash equilibria of the subgame following an offer (ω, n) in the reserve-ordered game are represented in Figure 6. 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 (9), it is optimal to set $\eta = 1$. If $\eta = 1$, then from (10) 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 $n > \omega$, 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 (9), in order to induce the proposer to choose blue notes, we must have $p < 1$. Furthermore, if $n > (1+\theta)\omega$, then from (10), in order to induce the responder to choose $p < 1$, we must have $\eta < 1$. An interesting property of this

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

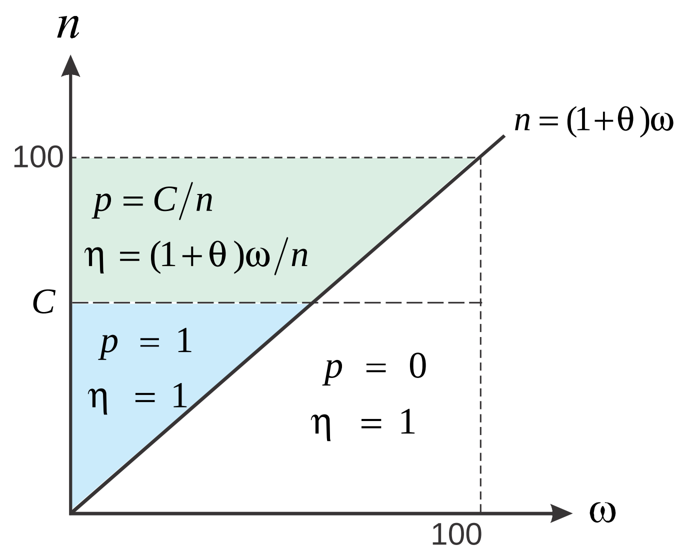


Figure 6: Nash equilibria following an offer (ω, n) in the reverse-ordered game.

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 in an interesting way. First, as θ increases the set of offers associated with a positive level of trade shrinks. This finding is consistent with the model under adverse selection. Second, in terms of the comparative statics of mixed-strategy equilibria, as θ increase the probability of fraud decreases (i.e., η increases). 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 will choose 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. 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

$$\max_{\omega,n,p} p\,(2\omega - n) \quad \text{s.t. } n - (1+\theta)\omega = 0 \;\text{ and }\; pn \le C. \tag{12}$$

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 (9).

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 Figure 7. 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 get rejected with positive probability; i.e., $p < 1$. So the model captures the notion that large note offers are less liquid; i.e., they have a greater probability of being rejected.[33]

Across all the optimal offers that solve (12) the expected surplus of the Proposer is

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

Usinf 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 $\mathbb{E}\left[\mathcal{S}_P\right] = (1-\theta)C/(1+\theta)$. By a similar reasoning the surplus of the Responder is $\mathbb{E}\left[\mathcal{S}_R\right] = \theta C/(1+\theta)$.

We illustrate the set of optimal offers in Figure 7. The grey 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 offers, $n = (1+\theta)\omega > C$, that are payoff equivalent but they are rejected with positive probability, $p < 1$. For instance, the proposer could make the complete 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.

[33] This property of our model is new. It differs from the version in Li, Rocheteau and Weill (2012). In that paper, agents have strictly concave utility which implies that for all $C > 0$ there is no fraud taking place in equilibrium, $\eta = 1$. Note, however, that in Section 3.B, they describe a version of the model in which the cost of fraud is random and fraud emerges an an equilibrium outcome.

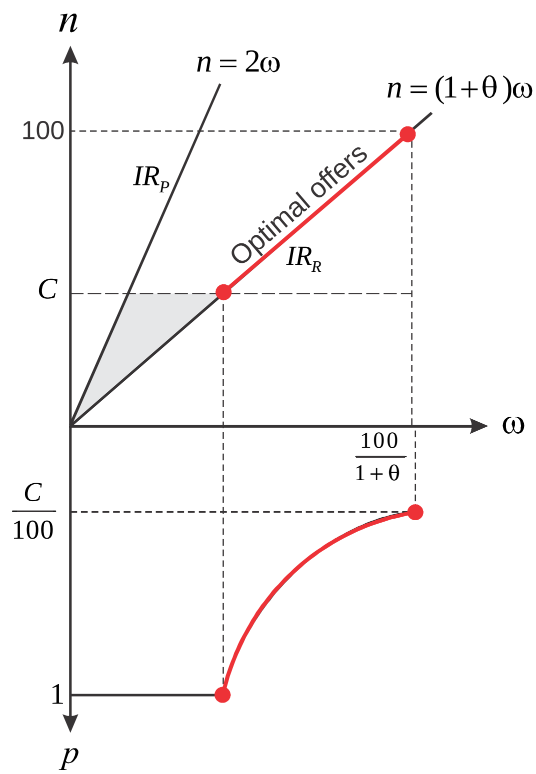


Figure 7: Bargaining under the threat of fraud

In summary for the theory of moral hazard treatment we distinguish two cases: one where the cost of fraud is zero and one where it is strictly positive. Under zero cost, acquiring red notes is a weakly dominant strategy, and therefore all offers should be rejected. If the cost is strictly positive, proposers should not acquire red notes. Offers that specify that the proposer retains a sufficiently large number of his blue notes; i.e., $n \leq C$, are accepted with certainty. Offers such that $n > C$ are only accepted with some probability that is increasing with C. The model also has predictions for out-of-equilibrium offers: (i) The fraction of blue notes and their price are positively correlated; (ii) Offers with a large number of notes are more likely to get rejected and to involve red notes.

Hypothesis 3 *(Moral Hazard)*

1. If $C = 0$, fraud can occur but no offer should be accepted.

2. If $C > 0$, then no fraud takes place and $n = (1+\theta)\omega$.

   (a) Offers such that $n \leq C$ are accepted.

   (b) Offers such that $n > C$ are accepted with probability C/n.

5 Liquidity choices

In the last set of experiments we let subjects determine how much liquidity they want to hold. The experiment design replicates the environment of New-Monetarist models (Lagos and Wright, 2005) where agents choose their money holdings before entering a decentralized market with pairwise meetings and bargaining. The rates of return of the notes are given to the subjects, which can be interpreted at the rate of return coming from an exogenous money growth rate in a stationary equilibrium (Lagos and Wright, 2005) or the rate of return of a storage technology (Lagos and Rocheteau, 2008). These sessions will allow us to determine whether subjects are willing to hold assets that are dominated in their rates of return and whether informational asymmetries regarding the value of an asset affect agents' willingness to hold that asset for liquidity purposes.

5.1 Investment in liquidity under complete information

Proposers are endowed with some amount of nonliquid wealth, W. The Proposer has the possibility to spend some of his wealth to purchase notes at some price $\phi \geq 1$ in terms of numéraire good or to keep his wealth in the form of non-liquid capital—capital that cannot serve as means of payment in pairwise meetings. The notes are redeemed at the end of the experiment for one unit of numéraire good. Given that $\phi \geq 1$, notes have a non-positive rate of return whereas the rate of return of the nonliquid wealth is 0; i.e., notes are dominated in their rate of return.

We first look at a Proposer's strategy. Provided that $\phi < 1$ purchasing more notes than the quantity that one intends to spend in a bilateral match is a strictly dominated strategy. So suppose that Proposers purchase the amount of notes that they plan to offer in a match. Let $p(\omega, n)$ denote the probability with which a randomly chosen Responder accepts the offer (ω, n). The best response problem of the Proposer is given by

$$\max_{\omega,n} \{p(\omega,n)(2\omega + W - \phi n) + [1 - p(\omega,n)]\,[W - (\phi - 1)n]\}\,. \tag{13}$$

With probability $p(\omega, n)$ the offer is accepted in which case the Proposer's payoff is composed of the value of its widgets, 2ω, and his remaining non-liquid wealth, $W - \phi n$. With complement probability, $1 - p(\omega, n)$, the offer is rejected in which case the Proposer's payoff is the sum of the value of his notes, n, augmented by the value of his non-liquid wealth, $W - \phi n$. The Proposer's problem can be rewritten more compactly as

$$\max_{\omega,n} \left\{-(\phi - 1)n + p(\omega, n)(2\omega - n)\right\}. \tag{14}$$

The first term, $\phi - 1$, is the cost of holding notes while the second term is the expected surplus from a pairwise meeting. From the best response of the Responder, we have $p(\omega, n) = \mathbb{I}_{\{n-(1+\theta)\omega\geq 0\}}$.[34] Using this condition, the Proposer's problem reduces to

$$\max_{\omega,n} \left\{-\phi n + 2\omega\right\} \mathbb{I}_{\{n-(1+\theta)\omega\geq 0\}}. \tag{15}$$

Moreover, ω cannot be greater than the amount of widgets held by the Responder and $\phi n \leq W$. It is clear from (13) that as long as $(1 + \theta)\phi < 2$, it is strictly optimal for the buyer to purchase $\min\{100, W/\phi\}$ notes, i.e., he will purchase enough notes to buy $100/(1 + \theta)$ widgets if he has enough wealth to do so. In the experiment we set $W/\phi = 100$ so that the buyer should spend all his wealth to buy exactly 100 notes. When $\phi \in \left(1, \frac{2}{1+\theta}\right)$ the model predicts rate of return dominance in the sense that agents accumulate notes that have a negative rate of return when they could hold illiquid wealth with a zero rate of return.

In Figure 8 we represent by a grey area the set of offers that are individually rational, $2\omega - \phi n \geq 0$ and $n - (1 + \theta)\omega \geq 0$, taking into account the cost for the Proposer to acquire notes. This set shrinks at the cost of acquiring notes increases.

5.2 Investment in liquidity under asymmetric information

We now introduce private information in the environment considered above. There are three types of notes: blue, orange, and red notes. For simplicity we restrict the Proposer's choice of notes to $n = 100$. However, the proposer is free to choose any type. The prices of notes are ordered as follows (where the superscript indicates the color of the notes):

$$\phi^b > \phi^o = 1 > \phi^r = 0.$$

[34] Here, we used the tie-breaking rule according to which offers that make the Responder indifferent between accepting or rejecting are accepted.

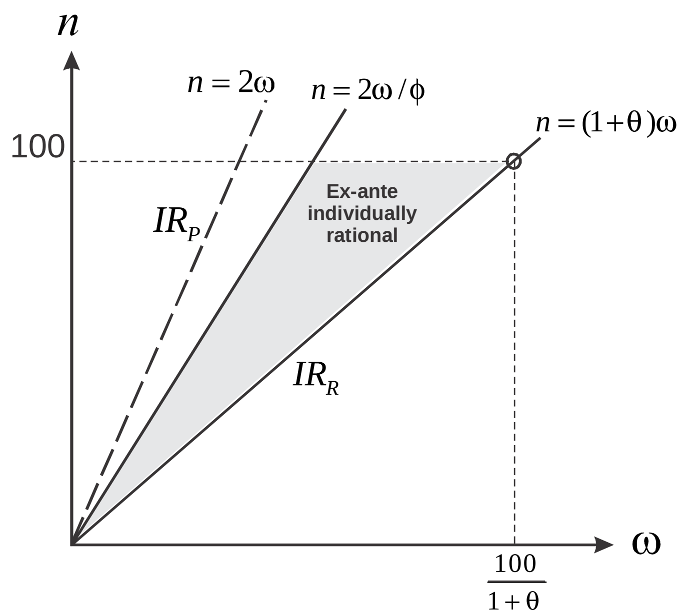


Figure 8: Liquidity choice

So blue notes are costly to hold since $\phi^b > 1$. There is no cost of holding an orange note since its purchase price is equal to its redemption value. Red notes can be acquired for free but they are worthless. As in the section on fraud, we assume that the Responder cannot distinguish orange notes from red ones.

A Proposer's strategy that consists in purchasing orange notes is weakly dominated by the one that consists in purchasing red notes. To see this, suppose that the Proposer purchases orange notes to make an offer (n, ω) such that $2\omega - n \geq 0$. If the offer is accepted, then the payoff of the Proposer is $-(\phi^o - 1)100 + 2\omega - n = 2\omega - n \geq 0$. If he had purchased red notes his payoff would be $2\omega > 0$, which is larger. If the offer is rejected, then the Proposer's payoff is 0, which is the payoff he would get from purchasing red notes. So as long as the Proposer anticipates that the offer will be accepted with positive probability, he should purchase red notes. As a result any individually rational offer with orange/red notes will be rejected by the Responder. By purchasing blue notes the Proposer can obtain a payoff $-\phi^b n + 2\omega$ with $n = (1 + \theta)\omega = 100$. As long as $\phi^b < 2/(1 + \theta)$, this payoff is strictly greater than the one from acquiring red or orange notes. So in equilibrium Proposers should accumulate blue notes despite their lower rate of return.

In summary the liquidity-choice treatment has two set of implications. When notes are perfectly recognizable agents are willing to hold these notes despite their negative rate of return because of their liquidity role. Second, if there are both high-return and low-return notes but high-return notes can be subject to fraud at zero cost, then agents should keep holding low-return notes as means of payment.

Hypothesis 4 *(Liquidity choice)*

1. (Liquidity Premia) If $\phi(1+\theta) < 2$, then proposers purchase notes despite their negative rate of return and they make the complete-information offer, $n = (1+\theta)\omega = 100$.
2. (Rate-of-return Dominance) Under private information, if $\phi^b(1+\theta) < 2$, then proposers choose blue (recognizable) notes despite their lower rate of return and they make the complete-information offer, $n = (1+\theta)\omega = 100$. Notes that are not recognizable (red or orange) are not accepted in trade.

6 Experiment Design

6.1 Basics

We conducted multiple experiment sessions in a computer laboratory at a large public university with 466 students as human subjects.[35] Students learned of experiments via posted advertisements and email announcements, and they registered to be in the subject pool through an online registration system. Days before each experiment session, an email was sent to the subject 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 salient earnings based on the decisions made, with final take-home amounts rounded up to the nearest quarter. The average take-home amount across all sessions was about $19 for about 75 minutes of participation. Table 1 displays basic information about the sessions and the subjects.

To facilitate experiment 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

[35] We conducted twenty one sessions but we only report thirteen for sake of clarity. For instance, we ran six sessions with unrepeated one-shot games and found results roughly consistent with the results presented here.

questions to test their comprehension about the payoffs associated with the different decision-making roles. After answering each question, the subject is told whether his or her answer was correct and a complete explanation of the correct answer. The instructions were identical across sessions except for minor changes in the description and questions that correspond to the specifics of the treatment.[36]

The decision-making stage consists of twenty rounds of one-shot interactions. Subjects are first randomly assigned into proposer and responder roles, which they maintain during all twenty rounds. They are then randomly and anonymously matched into the first one-shot interaction. For sessions in which nature chooses the terminal value of the notes, the terminal value is chosen by the computer independently across proposers in the round and independently within proposer across rounds. The information available to the subjects when making decisions depends on the specific treatment conditions described below. 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. At the end of the last round, the computer randomly selected one round, and all subjects were paid according to the decisions for that round. Each blue note is worth \$0.1 to both proposer and responder, and each widget is worth \$0.2 to the proposer and \$0.1 to the responder. Red notes have no value. To ensure that each session ends on time, decisions were made with explicit time constraints. Proposers were given 120 seconds 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 seconds 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 discussion below.

The questionnaire asks the subject to report personal information, such as sex, race, major, and so on. As shown in Table 1, the questionnaire data reveal a wide distribution of subjects, with higher proportions of females, engineering, and biological sciences students than in the university's undergraduate population.

6.2 Sessions, Treatments, and Hypotheses

The sessions correspond to fourteen treatment conditions in the five choice settings examined in the theory part of the paper. These settings are recapitulated in the following under the labels SI, SU, AS, MH, and L. We conducted a single benchmark Symmetric Informed (SI) session in which all proposers are commonly

[36] In the Appendix, we present the instructions for a representative session.

known to have blue notes. In the three Symmetric Uninformed (SU) sessions, neither proposer nor responder knows the color of the notes until after proposals and accept-reject decisions, but rather there is a commonly known probability at which a subject's notes are all blue or all red (iid across subjects). These sessions also allowed the proposers to use an on-screen calculator to calculate the final payoffs for different hypothetical offers before the actual offer was made. In the three Adverse Selection (AS) sessions, each corresponding to the same three probabilities of blue notes, $\pi \in \{0.5, 0.7, 0.9\}$, the proposer knows the color of her notes when making an offer, but the responder does not know the notes' color when deciding to accept or reject. The three AS sessions also had the on-screen calculator. In the three Moral Hazard (MH) sessions, the proposer chooses whether to have all blue or all red notes. Each of the three MH sessions considers one of three costs, $C \in \{0, 20, 60\}$, for purchasing 100 red notes. Note that the cost is expressed in tenth of dollars (or dimes) to make it comparable to the value of blue notes. The four Liquidity (L) sessions differ in the portfolio choice available to the proposer before making the offer. In L0, L1, and L2, the proposer chooses how many blue notes to purchase, with the cost of each note differing across the two sessions ($0.10 in L0, $0.11 in L1, $0.15 in L2), and the responder knows the notes' color. In L3, the proposer chooses whether to have all blue notes for $15, all orange notes for $10, or all red notes for $0. The responder can observe if the notes are blue but cannot distinguish between orange notes, which have the same value as blue notes, and red notes, which have no value.

7 Experiment Results

7.1 Summary Statistics and Figures

Panel (a) of Table 2 presents various summary statistics for each session. Panels (b)-(d) report a reduced set of similar statistics when the data are partitioned into accepted and rejected offers or into blue notes and red notes. These statistics provide cursory evidence of many patterns for which we provide formal statistical tests later. For example, the number of notes offered is higher, the price of widgets – defined as the number of notes offered per widget – is lower, and the acceptance rate is higher under Symmetric Informed (SI) than in each of the Symmetric Uninformed (SU), Adverse Selection (AS), and Moral Hazard (MH) sessions, all of which point to informational darkness as a hindrance to trade at both the extensive (the number of trades taking place) and intensive margins (the number of widgets traded). In all sessions, responders always made their decisions before their time limit expired, but there is some variation across sessions in how much time responders used. In the SI and SU sessions, proposers always made offers before time expired, but in the AS, MH, and L sessions, some proposers, ranging from 1% in MH2 and L1 to 10% in L3, did not make decisions within the allotted time.[37]

Figures 7 and 8 provide additional insights into the data. Figure 7 shows the average number of notes offered, the average number of widgets asked, and the average acceptance rate for each session by period. Every SI, SU, AS, and MH session shows a general trend of increasing notes offered over time. Widgets requested increase over time in the SI and SU sessions, and two of the three AS sessions (AS2 and AS3). No general trends in widgets offered are spotted in the other sessions. Acceptance rates generally exhibit larger variability than offer sizes, with much higher variability in acceptance rates in many of the AS and MH sessions than in session SI.

Figure 8 plots the distribution of offers by note type and acceptance for some representative sessions. The area of each circle corresponds to the number of observations with that notes-widget combination, and the same weighting scale is used across graphs. The dotted lines represent the bounds of individually rational offers with blue notes given a pooling equilibrium, and the inner, darker line is the average price (n/ω). We see larger variance in offers in SU2, AS2, and MH2 than in SI, which is confirmed in Table 2. Visual inspection also suggests that accepted offers have, on average, higher prices than rejected offers, a finding that holds up in all sessions except MH1 and L3 (see Table 2), both of which have very low acceptance rates.

7.2 Symmetric Information

The sessions under symmetric information (SI and SU) provides us with benchmarks relative to which we can assess the effects of informational frictions on market outcomes.

RESULT #1. Under complete information the median number of notes offered is 100, a vast majority of offers are accepted, and the average surplus share of the Responder is positive.

The average number of notes offered under complete information (SI) is 87 out of 100 (see Table 2). We reject the hypothesis that the average notes equals 100 (test statistic 8.21). (Given that responders'

[37] The masses at (0,0) in some sessions reflect the default offer made for when the proposer's time expired before making an offer.

endowment of notes is 100 the offer has a downward biais relative to the efficient one.) However, the more relevant median notes offered is 100 (not in table); 63% of offers include 100 notes. Overall, we see that subjects tend to offer 100 notes, which is consistent with the assumption of Pareto-efficient trades. The average widgets requested is 74, well within the [50,100] range of Pareto-efficient trades. Almost three-quarters of offers are accepted, thus indicating a high level of successful trades.[38] As seen in Figure 8, every accepted offer had a price of widget greater than or equal to 1, and accepted offers have, on average, higher prices than rejected offers (also see Table 2). The average price of accepted offers is $n/\omega = 1.21$, which implies an average surplus share to responders equal to $(n - \omega)/\omega = 21\%$. That some offers with price greater than 1 are rejected while offers with higher prices are more likely to be accepted is consistent with what is typically observed in ultimatum games, namely, that offers that share more of the surplus are more likely to be accepted. This behavior could be due to some subjects valuing fairness. The above evidence suggests that behavior is largely consistent with Hypothesis 1. The outcome is different from the unique subgame perfect equilibrium, where the entire surplus is captured by the proposer, possibly due to fairness considerations.

RESULT #2. The number of notes offered and the acceptance rate are significantly lower when subjects are symmetrically uninformed than under complete information. The responder's surplus share is largely unaffected.

Many clear patterns are seen when comparing session SI with the SU sessions. We see a monotonic decrease in average notes offered as the probability of blue notes (π) decreases. As the probability of blue notes decreases from $\pi = 1$ to $\pi = 0.9$ and $\pi = 0.7$ the number of notes offered drops from 87 to 80 and 73 while the probability that an offer is accepted falls from 73% to 38% and 40% (Table 2). As indicated in Table 3, the difference is statistically significant when dropping from $\pi = 0.9$ to $\pi = 0.7$, but not significant when dropping further still to $\pi = 0.5$. Hypothesis 1 is strongly rejected with respect to the SU sessions; the intensive margin of trade (the number of notes offered) is severely affected by the uncertainty about

[38] As a comparison, Duffy and Puzzello (2013) 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 later 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.

the value of the notes and subjects are unable to achieve Pareto-efficient trades even though the lack of information about the terminal value of notes is symmetric. The lower number of notes offered might also be the outcome of some risk sharing when subjects are averse toward risk. We find a monotonic increase in average offered price for widgets as the probability of blue notes (π) increases. As shown in Table 3, these price increases from SI to SU3 to SU2 to SU1 are statistically significant. In sessions SU1 ($\pi = 0.5$), SU2 ($\pi = 0.7$), and SU3 ($\pi = 0.9$), accepted offers had an average price of 2.40, 1.59, and 1.53, and rejected offers an average price of 1.27, 1.34, and 1.19, respectively. The implied expected surplus share of the responder, $(\pi n - \omega)/\omega$, was 20% (SU1), 11% (SU2), and 38% (SU3) for accepted offers, and -29% (SU1), -6% (SU2), and 7.1% (SU3) for rejected offers. Thus, as for SI, the responders required a sufficiently large surplus—on average about 20%—in order to accept a trade.

A striking difference between SI and the SU sessions is in the rate at which offers satisfy the responder's individual rationality constraint, $\pi n \geq \omega$. A fraction 99% of all offers in the SI session meet this constraint, but far fewer do in the SU sessions. Moreover, this number decreases significantly as the probability of blue notes drops: 98% in SU3, 89% in SU2, and 54% in SU1. Proposers had access to the online calculator, but it appears that their ability to use it to calculate viable offers was imperfect.[39] It also seems that some proposers made offers that would only be acceptable under the optimistic belief that those notes are blue.

In summary, introducing uncertainty about the value of the notes reduced significantly the subjects' ability to exploit the gains from trade, increased the frequency of rejected offers, reduced the size of the trade, and decreased the turnover of the asset.

7.3 Adverse Selection

RESULT #3. When proposers are privately informed a majority of offers are rejected. Moreover, the notes offered are lower than under SI but not uniformely lower than under SU. Prices are uniformely smaller.

There is a large number of offers that are rejected in each AS session (Table 2). In AS1 ($\pi = 0.5$) 70% of offers are rejected, while in AS2 ($\pi = 0.7$) 61% and in AS3 ($\pi = 0.9$) 53% are rejected. These rejection rates are much higher than in the SI session (27%), and significantly higher than the ones of the

[39] We also conducted versions of SU1-SU3 in which no calculator was provided. In those no-calculator sessions we found even lower rates of satisfying the responders IR constraint. This suggests that the calculator did help, though it helped only imperfectly.

SU sessions (except for $\pi = 0.7$ where they are equal); i.e., 65%, 61% and 42%. While a 70% rejection rate gives some support for the no-trade outcome under the intuitive criterion, it should be recalled that even pooling equilibria breaks down when $\pi < 0.5$.

The average number of notes and average number of offers accepted are higher in session SI than in each of the AS sessions (Table 2), and these differences are statistically significant at high levels (Table 3). The differences are also shown visually in Figure 9, which plots the means and 95% confidence intervals for all sessions. We identify the role of private information by comparing each AS session with its SU counterpart. Figure 10 extracts time series from Figure 7 and recombines AS and SU sessions to facilitate visual inspection of each of these three comparisons. The formal statistical tests shown in Table 3 reveal that in average notes offered are higher in the SU session for $\pi = 0.7$ and $\pi = 0.9$, but not when $\pi = 0.5$ (SU1 vs. AS1), and the acceptance rate only differs when $\pi = 0.9$ (SU3 vs. AS3). As the probability of blue notes (π) decreases, the average notes offered does not change significantly. So even though there is note retention in the form of fewer notes being offered in the AS sessions when compared with session SI, this retention can hardly be attributed to some signaling mechanism as the same phenomenon happened under symmetric information.

Tables 2 and 3 and Figure 9 also reveal that there is no clear pattern between the average price offered and π. However, prices are significantly higher under symmetrically uninformed than under asymmetric information for each level of π. Moreover, the expected surplus share of the responder for accepted offers based on prior beliefs, $\pi n/\omega - 1$, is very different from the one observed in the absence of private information. It is negative and equal to -25% when $\pi = 0.5$ and -1% when $\pi = 0.7$. Relatedly, the rate at which offers satisfied the responder's individual rationality constraint decreases as π decreases: 85% in AS3, 36% in AS2, and 15% in AS1. Only when π is sufficiently large (0.9) do we observe a surplus share positive and consistent with the one under symmetric information, about 20%. This finding suggests that responders do revise their prior beliefs after receiving offers but that this updating is not consistent with actual offers.

Overall, the behavior from the AS sessions is only mildly consistent with Hypothesis 2. Trade is lower at both the extensive and intensive margins in the AS sessions than in session SI. However, subjects do not appear to have coordinated on a single equilibrium in the AS sessions. Consistent with a separating equilibrium, proposers with blue notes offer, on average, fewer notes. However, the differences are small, and proposers' apparent attempts to signal quality do not appear to be recognized by the responders. If the signals were recognized, then blue notes should be accepted at higher rates than red notes, but we actually see, in Table 2 and Figure 9, either no difference (AS1) or the opposite (AS2 and AS3). Whether subjects could coordinate on a single equilibrium without an explicit coordinating device if given more time is unclear. In summary, asymmetric information generates similar phenomena than symmetric uncertainty: it significantly reduces the subjects' ability to exploit the gains from trade, it increases significantly rejection rates, it reduces the size of the trade, and it decreases the turnover of the asset.

7.4 Moral Hazard

RESULT #4. When fraud is costless a vast majority of offers are rejected but genuine notes are not fully eliminated.

A key result from the theory (Hypothesis 3.1) 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 finding in session MH1 when notes can be counterfeited at no cost ($C = 0$) 72% of all offers are rejected. It is a stark example of asset illiquidity generated by the threat of fraudulent practices. It is still a little surprising that there is any trade taking place given that producing fraudulent notes is a weakly dominant strategy, which in theory should shut down trade completely. The fact that some offers are accepted can be rationalized by the fact that 34% of offers involved blue notes. But then it is puzzling why some proposers acquired blue notes if they expected agents to accept some offers. Overall the finding that even severe informational asymmetries do trigger a complete market freeze is consistent across the adverse selection and moral hazard sessions in contrast with some predictions of the theory.

RESULT #5. When fraud is costly a majority of proposers acquire blue notes. Moreover, when the cost of fraud is higher than 60 percent of the value of blue notes, then fraud is close to 0.

Another key result of the model is that fraud should not take place if $C > 0$, whereas if $C = 0$ any outcome in terms of fraud is possible. In the data the relationship between the extent of fraud and the cost of fraud is more continuous. In all MH sessions, the percentage of proposers that select blue notes is statistically different than 100%, i.e., there is fraud taking place.[40] However, as the cost of fraud increases

[40] 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

from 0 in session MH1 to a low value ($C = 0.2$) in session MH2 the rate of blue notes almost doubles from about one third (34%) to about two thirds (63%). In the medium-cost Session MH3 ($C = 0.4$) about three quarters of proposers acquire blue notes. In the high cost sessions, MH4 to MH6, ($C = 0.6, 0.8, 1$), this fraction is over 90%, which we view as broadly consistent with a no-fraud equilibrium. Notice that in MH6 when $C = 1$ red notes are as costly as blue notes. Given that blue notes have a higher redemption value than red ones it is a weakly dominant strategy to accumulate blue notes, and it is strictly if there is a positive probability that an offer is rejected. Even though 45% of the offers are rejected there is still 5% of proposers who are choosing red notes.

RESULT #6. The number of notes offered and the acceptance rate are higher under high cost of fraud than under low cost of fraud.

Another prediction of the model is that the resalability constraint on notes is relaxed as the cost of fraud increases, and as a result subjects should offer a larger number of notes. The optimal number of notes offered should be between $100C$ and 100 but as the number of notes offered increases the acceptance probability should decrease. The notes offered in the experiments are consistent with the theory. We do observe in Tables 2 that the average number of notes offered increases as we go from the low-cost sessions MH1-MH3 ($n = 55, 58, 50$) to the high cost sessions MH4-MH6 ($n = 74, 74, 73$). However, the difference between MH1 and MH2 and between MH4, MH5, and MH6 are not statistically significant at normal levels, as seen in Table 4. This might be due to the fact that subjects are not very receptive to small changes in the cost of fraud.

Hypothesis 2b predicts that responders will be more likely to accept low offers than high offers. Indeed, if $n \leq C$ then $p = 1$ and if $n > C$ then $p = C/n$. In contrast to this hypothesis, in sessions MH2 and MH3, the average number of notes offered is higher for accepted offers ($n = 61$, 77) than for rejected offers ($n = 58$, 71). However, these differences are never statistically significant at normal levels. Holders of blue notes seem to be able to signal the quality of their notes in some meetings as the acceptance rates for blue notes in all MH sessions, 33%, 24%, and 46%, are higher or equal than the ones for red notes, 23%, 24%, and 44%. The attempts at signaling the quality of notes remain quite ineffective as responders are more likely

arrested, and 611 counterfeiting plants were suppressed. As documented by Mihm (2007), counterfeiting was a widespread phenomenon in the U.S. during the 19th century.

to reject offers than to accept them irrespective of the color of the notes.

Also in accordance with the theory average acceptance rates increase as we raise the cost of fraud. The acceptance rate jumps up from MH1 to MH3, from $p = 27\%$ to $p = 46\%$, and MH2 to MH3, from $p = 24\%$ to $p = 46\%$. The acceptance rate actually dropped slightly from Session MH1 to MH2, yet the difference is not statistically significant (see Tables 2 and 4). A previously indicated this could be due to the fact that subjects view the two environments with low cost of fraud, MH1 and MH2, as very similar.

Finally, in the following table we compute for the average offer in each session the rate of blue notes (η^{theory}) and the acceptance rate (p^{theory}) according to the theory, i.e., we compute the Nash equilibrium of the subgame of the reverse-ordered game that follows the average offer observed in the data. We see that while subjects accept too many offers when fraud is costless (MH1) they tend to accept too few offers when fraud is costly (MH2 and MH3). The rate of blue notes is too low given the average offer in MH2 but too high in MH3.

	MH1	**MH2**	**MH3**
n	55	58	74
ω	38	46	62
$p^{\text{data}}(\%)$	27	24	46
p^{theory}	*0*	*34*	*81*
$\eta^{\text{data}}(\%)$	34	63	92
η^{theory}	$[0,1]$	*78*	*85*

The general pattern is that the possibility of fraud hinders trade at both the extensive and intensive margins. Subjects do not coordinate on a no-fraud equilibrium even though proposers are retaining more assets as the cost of fraud decreases. We also note that the proposers are making offers with higher prices as the cost of fraud decreases. Thus, the behavior under the Moral Hazard setting shows important similarities to that in the Adverse Selection setting, i.e., we see proposers respond by both asset retention and price increases. Indeed, the responders react more to price than asset retention when deciding whether to accept or reject an offer. Though there is no statistically significant difference between the prices of accepted and rejected offers in Session MH1, there is in sessions MH2 and MH3 (test statistics -2.53 and -4.26, respectively).

7.5 Liquidity

When proposers choose their asset portfolios in the L1 and L2 sessions, Hypothesis 4(a) predicts that blue notes will be purchased despite their negative return (the purchase price of 10 notes is greater than the redeeming price, \$1) because of their liquidity return in pairwise meetings. Average notes offered in L1 ($n = 60$) and L2 ($n = 60$) are significantly different from 0 at high significance levels, as shown in Tables 2 and 4 and Figure 9. The purchase of blue notes is steady across rounds in both the L1 and L2 sessions, as seen in Figure 11.

The number of notes, however, is lower than the 100 notes that subjects would be supposed to acquire according to the theory. There are two factors that can help explain this discrepancy between the theory and the data. First, not all offers in the data are accepted, in contrast to what the theory predicts: 64% of all offers are accepted in L1 while 61% are accepted in L1. The lower acceptance rate reduces the liquidity return of notes and reduces the incentives to acquire notes in the first place. Second, proposers do not receive the whole surplus of the trade: the price of widgets in terms of notes is $1.21 > 1$ in L1 and $1.15 > 1$ in L2. This implies that the proposer's share in the match surplus is 79% in L1 and 85% in L2. A share less than 100% introduces a holdup inefficiency as the proposer makes an investment in liquidity but only gets a fraction of the return of that investment.[41] As a result of this inefficiency subjects should lower their investment in liquidity relative to what the theory predicts. To see the impact of these two factors (the risk of the offer being rejected and the proposer's share of the match surplus being less than 100%) on subjects' liquidity choices in the following table we compute the average holding cost of 10 notes, $\phi - 1$, and their expected liquidity return, $p(2\omega - n)/n$, for the sessions L1 and L2. We can see that in session L1 the holding cost of notes is lower than their liquidity return suggesting that subjects were under-investing in liquidity. However in session L2 the holding cost of notes and the liquidity return are almost equalized, in accordance with what the theory predicts.

	L1 ($\phi = 1.1$)	**L2** ($\phi = 1.5$)
Holding cost ($\phi - 1$)	10%	50%
Liquidity return ($\frac{p(2\omega-n)}{n}$)	40%	53.4%

In Session L0, which is provided for comparison with L1 and L2, the cost of blue notes implies no negative return if untraded. Indeed 10 notes before the matching phase cost \$1 and they are redeemed for exactly \$1 at the end of the experiment. This treatment where liquidity is not costly to hold corresponds to a Friedman

[41] The effect of an holdup inefficiency for agents' investment in liquidity has been emphasized in Lagos and Wright (2005) and Aruoba, Rocheteau, and Waller (2007) under Nash and proportional bargaining solutions. Even tough in our experiments subjects are playing an ultimatum game, the outcome is more consistent with a bargaining solution where the proposer does not have all the bargaining power, presumably due to fairness considerations. Such holdup inefficiency can help explain large welfare costs of anticipated inflation.

rule outcome. As would be expected, with no cost of holding blue notes in L0, we observe a higher number of blue notes purchased in L0 ($n = 82$) than in L1 and L2 ($n = 60$). This difference is large and statistically significant (see Table 4). We also expect offers in L0 to be similar to those in SI. We find that notes offered and the acceptance rate are both lower in L0 ($n = 82$ and $p = 62\%$) than in SI ($n = 87$ and $p = 73\%$), though not dramatically so, and prices are not statistically different in L0 and SI. The difference stems in part from some proposers not buying 100 (blue) notes even when there is no cost of holding blue notes. The fact that under the Friedman rule subjects do not satiate their liquidity needs by holding 100 notes is puzzling. Yet we see that practically all notes purchased are offered and at prices similar to those in SI. We thus see behavior in L0 to be similar to SI conditional on the number of notes purchased.

Hypothesis 4(b) tests subjects' choice of assets for payment purposes when some assets suffer from informational asymmetries. The theory predicts that subjects should accumulate the asset that is free from informational asymmetries but that has a lower rate of return—one should observe a rate-of-return dominance outcome in session L3. We do find that 37% of the subjects, on average, choose to hold blue notes despite their being dominated in their rate of return. So there is rate-of-return dominance in the data. However, the extent to which subjects choose blue notes is much less than the 100% that the theory predicts. In fact, 46% of the subjects choose red notes and 17% of the subjects choose orange notes, which runs counter to the prediction that orange/red notes will not be held. This should not happen in theory because orange/red notes should not be accepted by the responders. In the data (Table 2), however, 44% of the offers that involved red notes were accepted. That responders accept red/orange notes when the cost of acquiring red notes is zero is puzzling. We note, however, that the purchase of orange notes appears to trend downward in session L3, as seen in Figure 11. If subjects are indeed learning to avoid orange notes, then it is possible that with enough time, they will then learn to avoid red notes as well, thus leading all subjects to eventually hold only blue notes. Thus, although the data reject Hypothesis 4(b), there is also an indication that the subjects may eventually reach the predicted equilibrium but just have not done so yet.

8 Conclusion

We have presented a simple theory of OTC bargaining games under complete 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 studied the cases where: (i) agents are symmetrically informed about the terminal value of notes; (ii) agents are symmetrically uninformed; (iii) note-holders have private information; (iv) note-holders can take hidden actions to affect the terminal value of the notes. After having 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 bargaining game under complete 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, uncertainty about the value of the medium of exchange has a large negative effect on trades both at the extensive (fraction of offers that are accepted) and intensive (number of notes that are traded) margins even when information is symmetric. This suggests that certainty about the value of an object—its safety—is an important attribute for its role as a medium of exchange. Third, informational asymmetries matter more for liquidity when they originate from individuals' hidden actions (i.e., fraud) rather than being exogenous (pure adverse selection). However, even when the private information problem is very severe—e.g., fraud is costless—markets do not shut down completely. Fourth, subjects are willing to invest in notes that have a low rate of return provided that they are liquid and recognizable. Still, investment in liquidity tends to be too low relative what theory predicts.

Our model is simple and tractable and can be extended in various fruitful ways. For instance, our model can be used to study how incentives to acquire information matters for asset and market liquidity. One can also use our model to study other dimensions of collateralized trades, such as haircuts, and how these dimensions are affected by various informational frictions. More need to be done to understand individuals' portfolio choices in terms of liquid and illiquid assets, and how these choices matter for asset prices. We leave these different questions for future research.

References

[1] Arrow, Kenneth (1971). Essays in the Theory of Risk-Bearing. Chicago, IL: Markham Publishing Company

[2] Aruoba, S. Boragan, Guillaume Rocheteau and Christopher Waller (2007). "Bargaining and the value of money," Journal of Monetary Economics 54, 2636–2655.

[3] Banarjee, Abhijit and Eric Maskin (1996). "A Walrasian theory of money and barter," Quarterly Journal of Economics 111, 955–1005.

[4] Barnett, Harold (2012). "And Some with a Fountain Pen: Mortgage Fraud, Securitization and the Subprime Bubble." in How They Got Away with it: White-Collar Crime and the Financial Meltdown, edited by Susan Will, Stephen Handelman and David C. Brotherton. New York: Columbia University Press.

[5] Berentsen, Aleksander and Guillaume Rocheteau (2002). "On the efficiency of monetary exchange: how divisibility of money matters," Journal of Monetary Economics 49, 1621–1649.

[6] Berentsen, Aleksander and Guillaume Rocheteau (2003). "Money and the Gains from Trade," International Economic Review 44, 263-297.

[7] Berentsen, Aleksander and Guillaume Rocheteau (2004). "Money and information," Review of Economic Studies 71, 915–944.

[8] Bolton, Gary, and Axel Ockenfels (2000). "ERC: A theory of equity, reciprocity, and competition," The American Economic Review 90, 166-193

[9] Burdett, Kenneth, Alberto Trejos, and Randall Wright (2001). "Cigarette Money," Journal of Economic Theory 99, 117—142.

[10] Brown, Paul (1996). "Experimental Evidence on Money as a Medium of Exchange," Journal of Economic Dynamics and Control 20, 583-600.

[11] Cadsby, Charles, Frank, Murray and Maksimovic, Vojislav (1990). "Pooling, Separating, and Semiseparating Equilibria in Financial Markets: Some Experimental Evidence," Review of Financial Studies, vol. 3(3), 315-42.

[12] Camargo, Braz and Benjamin Lester (2013). "Subsidizing price discovery," Research Departement, Federal Reserve Bank of Philadelphia, Working paper no. 13-20.

[13] Camerer, Colin F. (2003). Behavioral Game Theory: Experiments in Strategic Interaction. Princton University Press.

[14] Cho, In-Koo and David Kreps (1987). "Signaling games and stable equilibria," Quarterly Journal of Economics 102, 179–221.

[15] Craig, Ben and Christopher Waller (2000). "Dual-currency economies as multiple-payment systems," Federal Reserve Bank of Cleveland, Economic Review 36, 2–13.

[16] Cuadras-Morató, Xavier (1994). "Commodity money in the presence of goods of heterogenous quality," Economic Theory 4, 579–591.

[17] DeMarzo, Peter and Darrell Duffie (1999). "A liquidity-based model of security design," Econometrica 67, 65–99.

[18] Duffie, Darrell, Gârleanu, Nicolae, and Lasse Pedersen (2005). "Over-the-counter markets," Econometrica 73, 1815–47.

[19] Duffie, Darrell (2012). Dark Markets: Asset Pricing and Information Transmission in Over-the-Counter Markets. Princeton Lectures in Finance.

[20] Duffy, John (2008). "Macroeconomics: A Survey of Laboratory Research," Working Papers 334, University of Pittsburgh, Department of Economics, revised Mar 2008.

[21] Duffy, John, and Jack Ochs. 1999. "Emergence of Money as a Medium of Exchange: An Experimental Study." American Economic Review, 89(4): 847–877.

[22] Duffy, John and Jack Ochs (2002). “Intrinsically Worthless Objects as Media of Exchange: Experimental Evidence,” International Economic Review 43, 637-73.

[23] Duffy, John, and Daniela Puzzello (2013). “Gift Exchange versus Monetary Exchange: Experimental Evidence”. American Economic Review (Forthcoming).

[24] Dutu, Richard, Ed Nosal, and Guillaume Rocheteau (2005). “The tale of Gresham’s Law,” Federal Reserve Bank of Cleveland Economic Commentary (October): 1 – 4.

[25] Eisfeldt, Andrea (2004). “Endogenous liquidity in asset markets,” The Journal of Finance 59, 1–30.

[26] Engineer, Merwan and Shouyong Shi (1998). “Asymmetry, imperfectly transferable utility, and the role of fiat money in improving terms of trade,” Journal of Monetary Economics 41, 153-183.

[27] Engineer, Merwan and Shouyong Shi (2001). “Bargains, Barter, and Money,” Review of Economic Dynamics 4, 188-209.

[28] Fehr, Ernst, and Klaus M. Schmidt (1999). "A theory of fairness, competition, and cooperation," The Quarterly Journal of Economics 114, 817-868.

[29] Fischbacher, Urs (2007). “z-Tree: Toolbox for Ready-made Economic Experiments,” Journal of Experimental Economics 10, 171–178.

[30] Forsythe, Robert, Lundholm, Russell, and Thomas Rietz (1999). "Cheap talk, fraud, and adverse selection in financial markets: some experimental evidence" Review of Financial Studies 12(3): 481-518.

[31] Forsythe, Robert, Kennan, John and Barry Sopher (1991). "An Experimental Analysis of Strikes in Bargaining Games with One-Sided Private Information," American Economic Review, vol. 81(1), 253-78, March.

[32] Green, Ed and Weber, Warren (1996). “Will the New $100 Bill Decrease Counterfeiting?” Federal Reserve Bank of Minneapolis Quarterly Review 20, 3–10.

[33] Gorton, Gary B and Andrew Metrick (2009). “Securitized Banking and the run out of Repo,” NBER Working Paper Series, Working Paper 15223.

[34] Gorton Gary B and Andrew Metrick, 2010. “Haircuts,” Review, Federal Reserve Bank of St. Louis, issue Nov, pages 507-520.

[35] Guerrieri, Veronica and Robert Shimer (2013) – only match I could find is: Guerrieri and Shimer (2012). “Dynamic Adverse Selection: A Theory of Illiquidity, Fire Sales, and Flight to Quality,” NBER Working Paper Series, Working Paper 17876.

[36] Holmstrom, Bengt and Jean Tirole (2001). “LAPM: A liquidity-based asset pricing model,” Journal of Finance 56, 1837–1867.

[37] Hopenhayn, Hugo and Ingrid Werner (1996). “Information, liquidity, and asset trading in a random matching game,” Journal of Economic Theory 68, 349–379.

[38] Hu, Tai-wei, John Kennan, and Neil Wallace (2009). "Coalition-proof trade and the Friedman rule in the Lagos-Wright model," Journal of Political Economy 117, 116–137.

[39] In, Younghwan and Julian Wright (2011). “Signaling Private Choices,” manuscript.

[40] Jacquet, Nicolas, and Serene Tan "Money and asset prices with uninsurable risks," Journal of Monetary Economics 59, 784–797

[41] Jevons, William (1875). Money and the Mechanism of Exchange, London: C. Kegan Paul.

[42] Kagel, John, Kim, Chung and Donald Moser (1996). “Fairness in Ultimatum Games with Asymmetric Information and Asymmetric Payoffs," Games and Economic Behavior, Elsevier, vol. 13(1), pages 100-110, March.

[43] Keys, Benjamin J., Tanmoy Mukherjee, Amit Seru, and Vikrant Vig (2010): “Did Securitization Lead to Lax Screening? Evidence from Subprime Loans,” Quarterly Journal of Economics 125, 307-362.

[44] Kiyotaki, Nobuhiro and Randall Wright (1989). “On Money as a Medium of Exchange,” Journal of Political Economy, Vol. 97, No. 4, 927-954.

[45] Kohlberg, Elon and Jean-Francois Mertens (1986). “On the Strategic Stability of Equilibria.” *Econometrica* 54, 1003-37.

[46] Krishnamurthy, Arvind and Annette Vissing-Jorgensen (2012). “The Aggregate Demand for Treasury Debt,” Journal of Political Economy, April 2012.

[47] Lagos, Ricardo (2010). "Asset prices and liquidity in an exchange economy," Journal of Monetary Economics 57, 913-30.

[48] Lagos, Ricardo and Guillaume Rocheteau (2008). "Money and capital as competing media of exchange," Journal of Economic Theory 142, 247-258.

[49] Lagos, Ricardo and Guillaume Rocheteau (2009). “Liquidity in asset markets with search frictions,” Econometrica 77, 403–426

[50] Lagos, Ricardo and Randall Wright (2005). “A unified framework for monetary theory and policy analysis,” Journal of Political Economy 113, 463–484.

[51] Lester, Benjamin, Postlewaite, Andrew and Randall Wright (2011). "Information and Liquidity," Journal of Money, Credit and Banking, vol. 43, pages 355-377, October.

[52] Li, Yiting (1995). “Commodity money under private information,” Journal of Monetary Economics 36, 573–592.

[53] Li, Yiting, Guillaume Rocheteau and Pierre-Olivier Weill (2011). “Liquidity and the threat of fraudulent assets,” Working Paper.

[54] Li Yiting, Guillaume Rocheteau and Pierre-Olivier Weill (2012). “Liquidity and the threat of fraudulent assets,” Journal of Political Economy 120, 1223-1224.

[55] Mailath, George, Okuno-Fujiwara, Masahiro, and Andrew Postlewaite (1993). “Belief-based refinements in signaling games,” Journal of Economic Theory 60, 241–276.

[56] Mihm, Stephen (2007). A nation of counterfeiters: Capitalists, con men, and the making of the United States, Cambridge, Harvard University Press.

[57] Mitzkewitz, Michael and Rosmarie Nagel (1993). "Experimental Results on Ultimatum Games with Incomplete Information," International Journal of Game Theory, Springer, vol. 22(2), pages 171-98.

[58] Nosal, Ed, and Guillaume Rocheteau (2011). Money, Payments, and Liquidity. MIT Press, Cambridge.

[59] Nosal, Ed and Neil Wallace (2007). “A model of (the threat of) counterfeiting,” Journal of Monetary Economics 54, 229–246.

[60] Plantin, Guillaume (2009). “Learning by holding and liquidity,” Review of Economic Studies 76, 395–412.

[61] Rabin, Matthew (2000). "Risk aversion and expected-utility theory: A calibration theorem," Econometrica 68, 1281-1292.

[62] Rocheteau, Guillaume (2009). “A monetary approach to asset liquidity,” Working Paper of the Federal Reserve Bank of Cleveland 09-01.

[63] Rocheteau, Guillaume (2011). “Payments and liquidity and adverse selection,” Journal of Monetary Economics.

[64] Rupert, Peter, Martin Schindler, Andrei Schevchenko, and Randall Wright (2000). "The search-theoretic approach to monetary economics: A primer," Economic Review of the Federal Reserve Bank of Cleveland, 4th Quarter, 10-28.

[65] Shi, Shouyong (1995). “Money and Prices: A Model of Search and Bargaining,” Journal of Economic Theory 67, 467-496.

[66] Shi, Shouyong (1997). "A divisible search model of fiat money," Econometrica 65, 75–102.

[67] Trejos, Alberto (1997), “Incentives to produce quality and the liquidity of money,” Economic Theory 9, 355–365.

[68] Trejos, Alberto (1999), “Search, bargaining, money and prices under private information,” International Economic Review 40, 679–695.

[69] Trejos, Alberto, and Randall Wright (1995). “Search, Bargaining, Money and Prices,” Journal of Political Economy 103, 118-141.

[70] Velde, François, Weber, Warren, and Randall Wright (1999). "A model of commodity money, with applications to Gresham's law and the debasement puzzle," Review of Economic Dynamics 2, 291–323.

[71] Williamson Stephen (2002). "Private money and counterfeiting," Federal Reserve Bank of Richmond, Economic Quarterly 88, 37–57.

[72] Williamson, Stephen and Randall Wright (1994). "Barter and monetary exchange under private information," American Economic Review 84, 104–123.

Appendix 1: Bargaining under adverse selection when red notes are valuable

We now consider the case where red notes have a positive terminal value, $\rho \in (0, 1)$.

Intuitive criterion. From the same logic as explained above, no pooling equilibrium exists. The equilibrium selected by the intuitive criterion is the Pareto-dominant equilibrium among all separating equilibria. In this separating equilibrium, the holder of red notes makes the following offer:

$$(\omega^L, n^L) = \arg\max_{\omega,n} (2\omega - \rho n) \quad \text{s.t. } \rho n - \omega \geq 0, \tag{16}$$

and $(\omega, n) \in [0, 100]^2$. The solution is $n^L = 100$ and $\omega^L = 100\rho$. The proposer spends all his notes and asks for an amount of widgets that leaves no surplus to the responder. The surplus of the proposer is 100ρ. This offer is represented in Figure 9 at the intersection of the curve labelled IR_R^ρ and the feasibility constraint $n = 100$.

Let us turn to the holder of blue notes. He makes an offer that maximizes his surplus subject to the responder's participation constraint and red-note holder incentive compatibility constraint:

$$(\omega^H, n^H) = \arg\max_{\omega,n} (2\omega - n) \tag{17}$$

$$\text{s.t. } n - \omega \geq 0 \tag{18}$$

$$2\omega - \rho n \leq 100\rho. \tag{19}$$

According to the incentive-compatibility condition, (19), the surplus of the proposer with red notes, who imitates the offer $2\omega - \rho n$, must be less than his surplus if he makes the offer $(\omega^L, n^L) = (100\rho, 100)$, which equals 100ρ. The solution of this program is such that (18) and (19) hold at equality; i.e., $n^H = \omega^H = \rho 100/(2-\rho)$. This offer is represented in Figure 9 at the intersection of the curve labelled IR_R^1 and the curve labelled IC_P^L. The surplus of the blue-note proposer is $\rho 100/(2 - \rho)$.

It is worthwhile to note the following properties of the separating equilibrium. First, the proposer with blue notes retains a fraction $2(1-\rho)/(2-\rho)$ of his notes. Second, he purchases fewer widgets than the proposer with red notes. Third, as ρ increases; i.e., as the adverse selection problem becomes less severe, asset retention decreases. Finally, the separating outcome is independent of π.

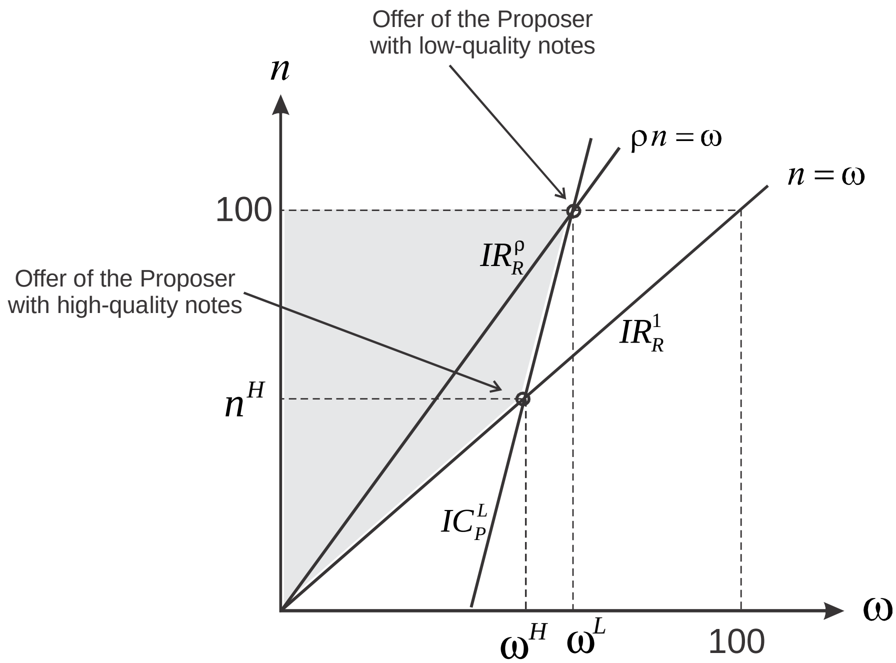


Figure 9: Separating equilibrium under adverse selection

Undefeated pooling equilibrium. Another interesting equilibrium is the best pooling equilibrium from the view point of a proposer with blue notes. The pooling offer solves

$$\max_{\omega,n} (2\omega - n) \quad \text{s.t.} \quad [\pi + (1-\pi)\rho]\, n - \omega \geq 0.$$

and $(\omega, n) \in [0, 100]^2$. Provided that $\pi + (1-\pi)\rho > 0.5$, the solution is $n = 100$ and $\omega = [\pi + (1-\pi)\rho]\, 100$. The payoff of the proposer with blue notes is $\{2\, [\pi + (1-\pi)\rho] - 1\}\, 100$. This payoff is larger than the one at the separating equilibrium if $\pi > (1-\rho)/(2-\rho)$. So a pooling outcome is undefeated in the sense of Mailath, Okuno-Fujiwara and Postlewaite (1993) if the probability of blue notes is high and the value of the red notes is not too low.

Appendix 2: Bargaining under adverse selection and the intuitive criterion

In this Appendix we show that under the intuitive criterion, and omitting fairness considerations, $\theta = 0$, there cannot exist a pooling equilibrium with $\omega > 0$ and $n > 0$. To see this, suppose there is a pooling offer, $(\bar{\omega}, \bar{n})$, with $\bar{\omega} > 0$ and $\bar{n} > 0$ in a proposed equilibrium. For this offer to be accepted in equilibrium, it must be that the responder's surplus is positive if notes are of high quality, i.e., $\bar{n} - \bar{\omega} > 0$. In order to show that the pooling offer cannot be part of an equilibrium, consider the following deviating offer by the proposer: $\omega' = \bar{\omega} - \varepsilon$ and $n' = \bar{n} - 3\varepsilon$. The proposer offers fewer notes in exchange for fewer widgets. We assume that notes and widgets are divisible so that $\varepsilon > 0$ can be made arbitrarily small. The payoff of a proposer with blue notes is $2\omega' - n' = 2\bar{\omega} - \bar{n} + \varepsilon$. So the proposer with blue notes is made better off. The payoff of a proposer with red notes is $2\omega' = 2\bar{\omega} - 2\varepsilon$. The proposer with red notes is made worse off. Moreover, if notes are blue, the surplus of the receiver is $-\omega' + n' = -\bar{\omega} + \bar{n} - 2\varepsilon$. Provided that $\varepsilon < (\bar{n} - \bar{\omega})/2$ this surplus is positive. According to the intuitive criterion the offer (ω', n') should be attributed to a proposer with blue notes and it should be accepted. Therefore, the proposed equilibrium is based on beliefs that violate the intuitive criterion.

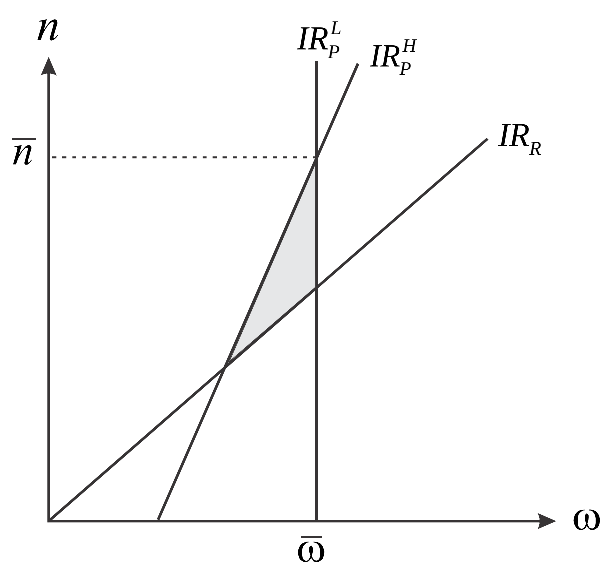
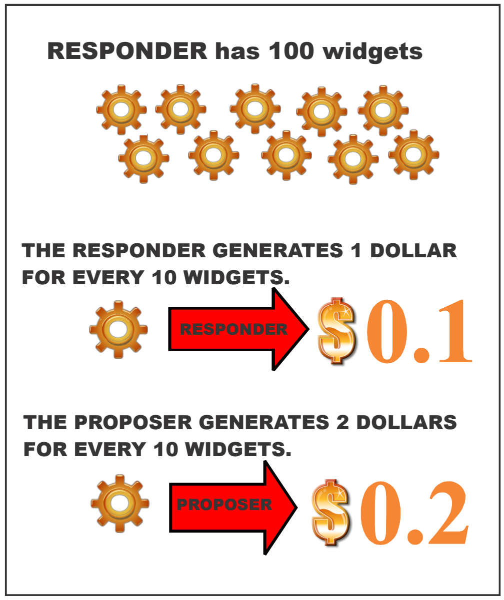


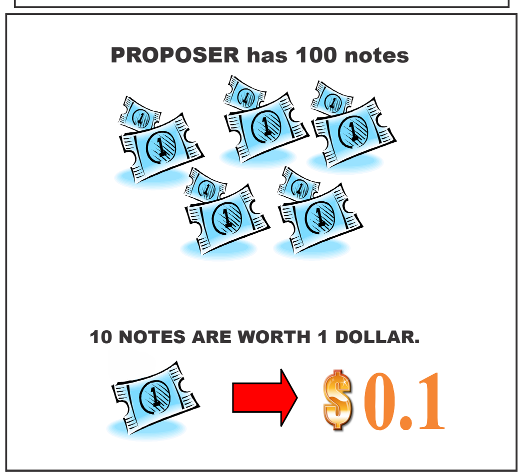
Figure 10: No pooling equilibrium under the intuitive criterion

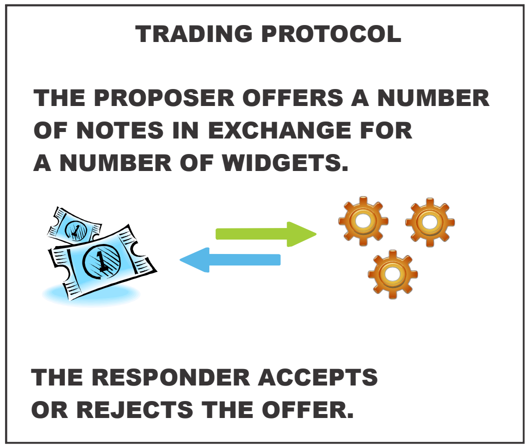
In Figure 10, offers of the type (ω', n') are represented by the grey area. The curve labelled IR_P^L is the indifference curve for a proposer with red notes (the set of offers such that $\bar{\omega} = \omega$) and the one labelled IR_P^H is the indifference curve for a proposer with blue notes (the set of offers such that $2\omega - n = 2\bar{\omega} - \bar{n}$). The curve labelled IR_R is the set of trades that yield zero surplus to the responder who attributes the average quality to the notes; i.e., $\omega = \pi n$. From the fact that $\bar{n} - \bar{\omega} > 0$ the curve IR_R is located below the offer at the proposed equilibrium, $(\bar{\omega}, \bar{n})$. It is clear from the figure that the set of offers that destroy a proposed pooling equilibrium is never empty. Since there cannot be a separating equilibrium, where the proposer with blue notes purchases widgets (otherwise the proposer with red notes would want to imitate the offer), the only equilibrium that survives the intuitive criterion is the one where no trade takes place; i.e., $\bar{\omega} = \bar{n} = 0$. This outcome corresponds to a situation where the adverse selection problem is so severe that it leads to a market breakdown.

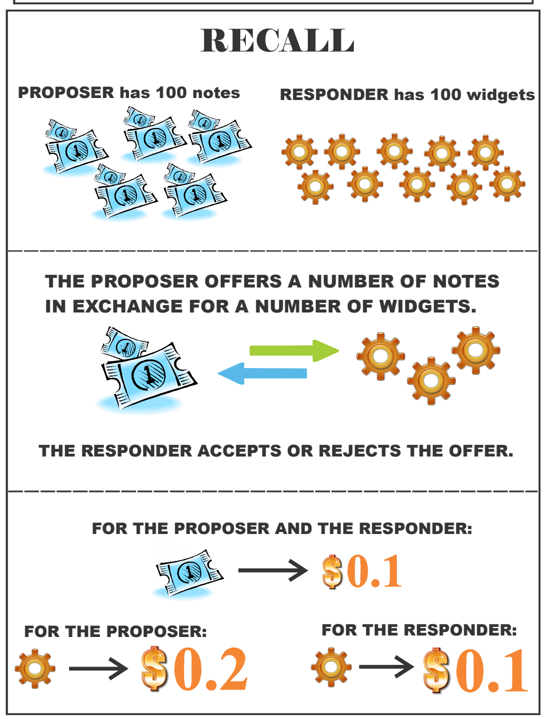
Appendix 3a: Instructions for the complete information case

Subjects were shown the following figures to summarize the instructions of the experiments with full information.

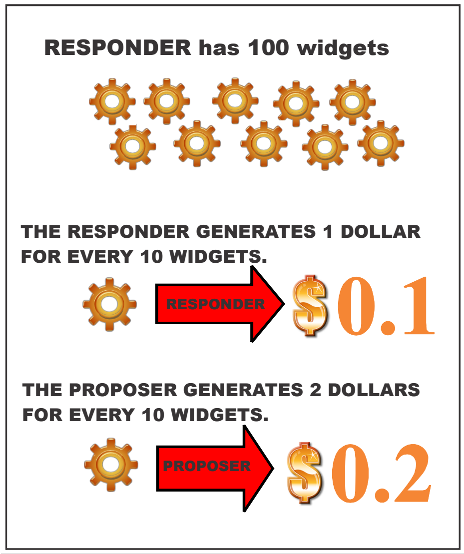


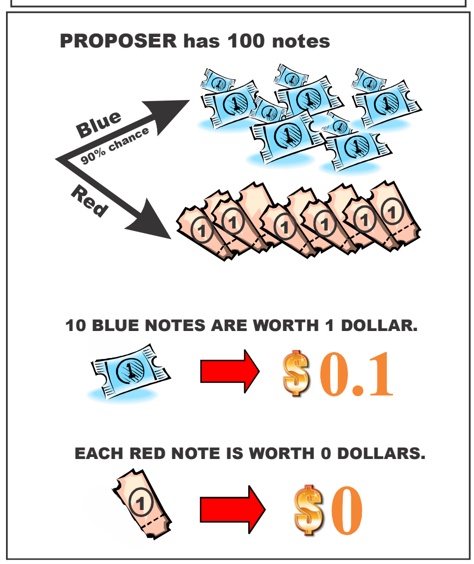


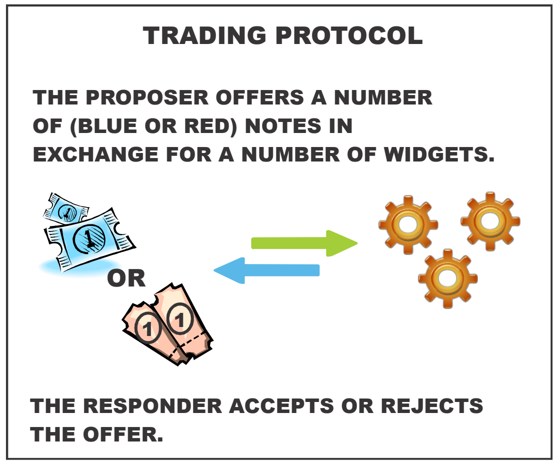

TRADING PROTOCOL
THE PROPOSER OFFERS A NUMBER OF NOTES IN EXCHANGE FOR A NUMBER OF WIDGETS.
THE RESPONDER ACCEPTS OR REJECTS THE OFFER.

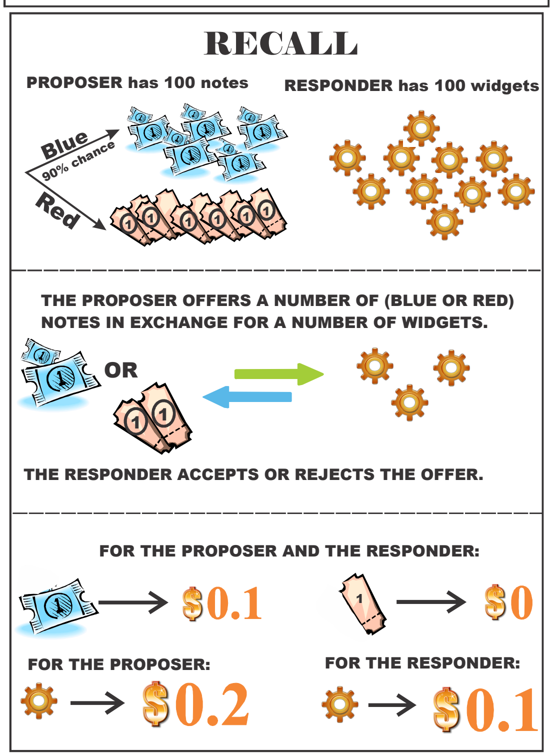

RECALL
PROPOSER has 100 notes
RESPONDER has 100 widgets
THE PROPOSER OFFERS A NUMBER OF NOTES IN EXCHANGE FOR A NUMBER OF WIDGETS.
THE RESPONDER ACCEPTS OR REJECTS THE OFFER.
FOR THE PROPOSER AND THE RESPONDER:
$0.1
FOR THE PROPOSER:
$0.2
FOR THE RESPONDER:
$0.1

Appendix 3b: Instructions for the adverse selection case

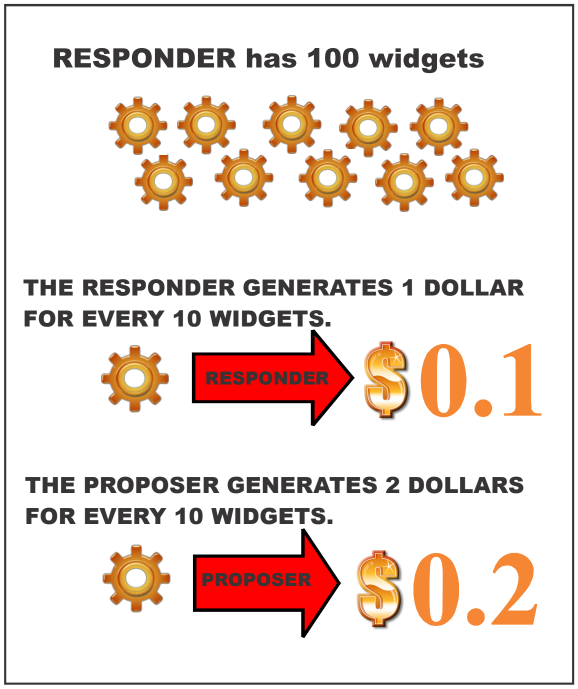


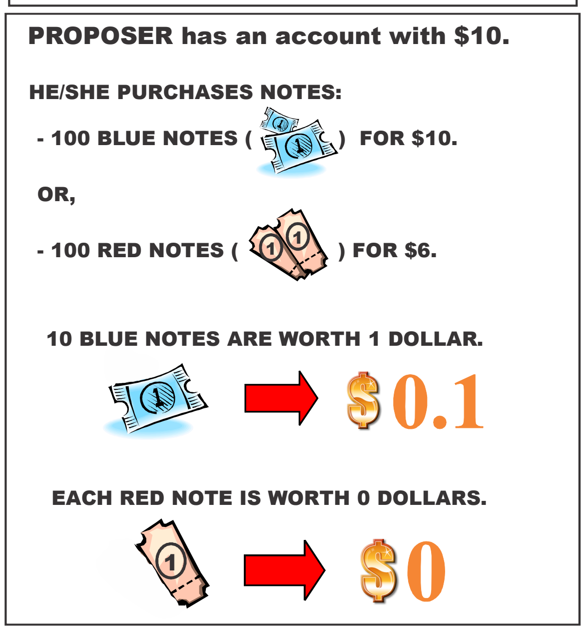



TRADING PROTOCOL
THE PROPOSER OFFERS A NUMBER OF (BLUE OR RED) NOTES IN EXCHANGE FOR A NUMBER OF WIDGETS.
OR
THE RESPONDER ACCEPTS OR REJECTS THE OFFER.


RECALL
PROPOSER has 100 notes
RESPONDER has 100 widgets
Blue
90% chance
Red
THE PROPOSER OFFERS A NUMBER OF (BLUE OR RED) NOTES IN EXCHANGE FOR A NUMBER OF WIDGETS.
OR
THE RESPONDER ACCEPTS OR REJECTS THE OFFER.
FOR THE PROPOSER AND THE RESPONDER:
$0.1
$0
FOR THE PROPOSER:
$0.2
FOR THE RESPONDER:
$0.1

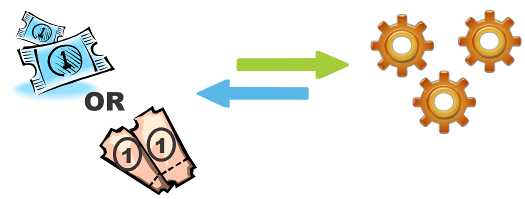
Appendix 3c: Instructions for the moral hazard case





TRADING PROTOCOL

THE PROPOSER OFFERS A NUMBER OF (BLUE OR RED) NOTES IN EXCHANGE FOR A NUMBER OF WIDGETS.

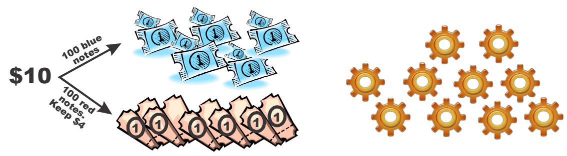


THE RESPONDER WHO CANNOT OBSERVE THE COLOR OF THE NOTES ACCEPTS OR REJECTS THE OFFER.

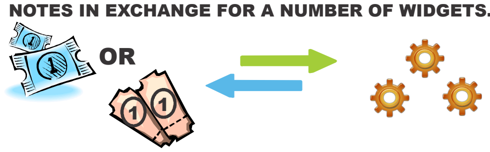
RECALL

PROPOSER has $10

RESPONDER has 100 widgets



THE PROPOSER OFFERS A NUMBER OF (BLUE OR RED) NOTES IN EXCHANGE FOR A NUMBER OF WIDGETS.



THE RESPONDER ACCEPTS OR REJECTS THE OFFER.

FOR THE PROPOSER AND THE RESPONDER:

FOR THE PROPOSER:

FOR THE RESPONDER: