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Abstract

We test in a controlled laboratory environment whether traders in a bilateral exchange internalize the impact of their actions on market prices better than in a large market. In this model, traders choose asset holdings, constrained by a technology frontier. Next, each trader experiences a random shock which makes only one type of asset profitable. In a general equilibrium environment with incomplete markets, this leads to pecuniary externalities because traders increase scarce asset holdings beyond what is socially optimal. This behavior is especially exacerbated in large experimental markets as traders fail to internalize the impact of their actions on prices. We find that when markets are incomplete, a bilateral exchange can slightly mitigate the extent of pecuniary externalities, and weakly increase welfare.

Keywords: pecuniary externalities, incomplete markets, general equilibrium, experimental market games, walrasian equilibrium

JEL codes: D51, D82, G10, C72, C92

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1 Introduction

When banks are subject to future idiosyncratic liquidity shocks, asset allocation becomes much more salient. This is particularly true in an environment where markets are incomplete (no insurance). In such case, the level of reserves that each bank chooses to hold ex-ante (prior to the shock) will affect the price and level of liquidity available ex-post. Thus, the individual action of each bank can lead to a wedge between the social and private value of liquidity.

In macro financial literature, the distortion in market prices is known as a pecuniary externality. Theory suggests that market size is an important factor in determining the extent of such externalities. In this paper, we use an experimental approach to study the salience of market size in incomplete markets. We show that a bilateral exchange, which is common in money markets, can enhance welfare in a general equilibrium model with incomplete markets by mitigating the extent of pecuniary externalities.

We find that in a competitive format (CM) with four traders on each side of the market,[1] asset allocation quickly approaches the predicted competitive equilibrium values. In a bilateral exchange, which can be characterized as a decentralized market (DM), the gain in efficiency is four consumption units relative to the CM, or about one-tenth of the predicted efficiency increase.[2] While it may seem intuitive that a bank should be able to efficiently satisfy its liquidity needs in a CM, this type of market actually leads to a larger wedge between the social and private values, thereby distorting the value of liquidity. An environment with a social planner does not run into this problem, because the social planner is able to internalize the impact of asset allocation. Specifically, a social planner does not take prices as given, as is the case in the CM, which results in a slightly different optimization process. One possible solution then, to pecuniary externalities, is to introduce a friction to the trading process which helps agents internalize the impact of asset reallocation.

The theoretical foundation of our experiment is based on the work of He and Kondor (2012, 2016). In our environment, a bank (or more generally a representative agent) decides how to allocate holdings between two available assets (x, y), subject to some existing technology. This constraint can be characterized as a possibility production frontier (PPF) with a changing opportunity cost. The PPF is biased such that the supply of one asset (x) is scarce relative to the other asset (y). The selection of (x, y) holdings takes place prior to a future idiosyncratic shock, which makes only one type of asset profitable for each agent. These shocks, while independent across periods, are also constrained such that in each

[1]Our competitive market has similarities to other centralized formats, such as clearinghouses and/or trading posts. We discuss how our format is related to other centralized formats in greater detail further below.

[2]We offer possible explanations for the smaller than predicted efficiency gains in Section 4.

period exactly one-half of the market participants will experience one type of shock and one-half will experience the other type of shock. Depending on treatment, players then trade the nonprofitable assets in either a CM or DM format. The model predicts that a representative agent will choose to hold more x (the scarce good) in the CM format compared to the DM format.

We find evidence of hoarding behavior in the CM, where the the median holding of x is 26 percent higher. This behavior leads to a wedge between the social and private values of the scarce asset. The wedge can be interpreted as a pecuniary externality. Agents overdemand the scarce asset without considering the impact of the sum of their individual actions, which lead to a suboptimal outcome. Pecuniary externalities tend to appear more frequently in markets that are imperfect or incomplete. We present an environment with incomplete markets, where banks do not have access to state-contingent contracts which can insure against idiosyncratic shocks.

In our experimental design, we abstract from the price formation process and focus solely on the subjects' allocation decisions. Therefore, the market clearing condition, from which the terms of trade are derived, is automated. The price at which trade occurs depends on the relative market supply. Players who face an x-shock only find x profitable, and therefore offer y in exchange for x. Similarly, players who experience a y-shock find y profitable and offer x in exchange for y. In the CM, our algorithm aggregates the excess supply[3] of both assets in the market, determines the (relative) price and then executes trade on behalf of all players. The automation allows us to reduce the cognitive load of our subjects and speed up the game.

In the bilateral exchange (DM), players from opposite sides of the market are randomly matched in pairs. In this case, our algorithm simply exchanges the non-profitable goods across players. Thus the terms of trade in DM vary across the randomly matched pairs. It is important to note that while in the CM, the trading group remained the same throughout the session, in the DM, the pairs were randomly matched each round. Random matching makes coordination more difficult to achieve. Therefore, our result can be interpreted as a lower bound on the efficiency gain compared to a partners matching protocol.[4]

A number of recent papers have highlighted the role of institutions in market outcomes. Lei and Noussair (2002) use an experimental approach to study market outcomes in an optimal growth model. They find that the market treatment (similar to the CM in our paper) has a strong tendency to converge to the optimal steady state, in both consumption and capital.

Some experimental studies consider the possibility that market institutions arise en-

[3]We define the excess supply of x as the amount of x deemed not profitable across all players, and apply the same definition to determine the excess supply of y.

[4]We would like to note that partners matching should not necessarily be interpreted as collusion, because each subject would still be acting in their own best interest.

dogenously. For example, Camera, Goldberg and Weiss (2016) suggest that in order to fully understand the emergence of money, the choice of institution is important and should therefore be endogenized within the model. Crockett, Smith and Wilson (2009) show that a bilateral exchange dominates an impersonal exchange (CM) in a two good production and consumption economy. Kimbrough, Smith and Wilson (2008) find that CM is preferred when traders are in separate locations and require multilateral exchanges.

Our paper is also related to the literature on static general equilibrium models in the laboratory, which use more complex environments with input and output markets. The results on whether these markets converge to a competitive equilibrium remain mixed. For example, Goodfellow and Plott (1990) find evidence of convergence, while Lian and Plott (1998) and Noussair et al. (1995) find that a considerable amount of economic activity occurs outside of the predicted competitive equilibrium. For an overview of the early literature as well as the recent macro experimental literature see Crockett (2013) and Duffy (2016). In our experiment, we show convergence to the predicted competitive equilibrium, and movement toward the predicted equilibrium in the DM over time. This indicates that in the DM format, subjects learn to behave more optimally.

Furthermore, we omit money from our experimental design, which means that goods are priced in relative terms. This feature allows us to simplify the number of items the agents hold, and to work with real variables, which are key to the decision making process. We provide a screen-shot of the graphical user-interface in Figure 1. The subjects only need to select a point on the PPF to specify a desired holding of (x, y). The idiosyncratic shocks, which follow the allocation decision, determine the type of asset that is profitable, and the automated market clearing facilitates the exchange of assets between the participants.

This experiment has features similar to the market game of Shapley-Shubik (1977) and a two-good exchange economy of Duffy, Matros and Temzelides (2011). Our design can be interpreted as traders exchanging assets in a trading post. However, our trading algorithm imposes optimal bids in order to simplify the decision making process of the subjects. We confirm the findings of Duffy et al. (2011), which suggest that as the number of traders increases, subject asset holdings approach a Walrasian equilibrium.

The results presented in this paper are important not only from a policy perspective, but also as a complement to existing literature. We demonstrate a situation where a bilateral exchange (DM) is not inferior to a competitive market (CM). In much of the previous literature, the DM format was found to be less efficient.[5] For example, Kugler et al. (2006) provide experimental evidence that when goods are homogeneous, the CM format will always dominate because traders can obtain higher surplus in the CM relative to the DM.

[5] We abstract from the role of market formats in aggregating information. For recent experimental evidence, see Asparouhova and Bossaerts (2017).

Similarly, Rud and Rabanal (2016), using an evolutionary approach, show that the DM is less efficient compared to posted offer and CM formats. However, when markets exhibit some sort of imperfections, we can no longer rely on centralized markets to provide superior outcomes. In fact, as Keynes wrote decades ago, market imperfections and uncertain future can lead to missing markets, price rigidities and a decision process that is closer to a simple rule of thumb or a collective market psychology, rather than rational evaluation of possible future scenarios (Magill and Quinzii, 2002).

According to He and Kondor (2012, 2016), pecuniary externalities help explain the cyclical behavior of capital in business cycles. They suggest that when agents make investment decisions prior to the realization of uninsured idiosyncratic shocks, it leads to excessive investment in booms and excessive hoarding of cash (or underinvestment) in busts. This inefficient hording due to redistribution of rents is also observed in models of liquidity. For example, Chapter 7 of Holmström and Tirole (2011), which draws from Malherbe (2014), illustrates how adverse selection and uninsurable idiosyncratic liquidity shocks can lead to precautionary hoarding. Davis (2017) provides experimental evidence of a modified version of Allen, Carletti and Gale (2009) where players (or banks) in a complete network can fail to fully insure themselves in a CM. Similarly, Gale and Yorulmazer (2013) emphasize that inefficient hoarding is a robust phenomenon in a laisser-faire equilibrium.

Dávila and Korinek (2017) provide a comprehensive theoretical framework that analyzes two types of pecuniary externalities, collateral and distributive. In this paper, we focus on the latter. The existence of collateral or credit constraints can also generate pecuniary externalities (Lorenzoni, 2008). Bosch-Domenech and Silvestre (1997) study whether credit tightness affects economic activity and market prices in the laboratory. They find that in a high-credit environment, the effects are minor and unsystematic, and that in a low credit environment, the effects are substantial, on both quantity and relative price. Fostel and Geanakoplos (2008) develop a richer framework in which assets also have value as collateral. An experiment by Cipriani et al. (2017) shows deviations from the law of one price when assets have a collateral value.

The rest of the paper is organized as follows: section 2 describes our environment, section 3 details the laboratory procedures, section 4 presents the results and lastly, section 5 discusses our main findings. Appendix A shows the solution to the optimization problem. Appendix B includes instructions used in experimental sessions in the LEEPS Lab in the University of California, Santa Cruz.[6]

[6]The Spanish version of instructions, used at the Universidad del Rosario, as well as the data collected from both labs are available at `https://github.com/rabsjp/pecuniary`

2 The environment

Our environment is motivated by the work of He and Kondor (2012, 2016), where ex-ante decisions of market participants lead to less than optimal outcomes following idiosyncratic shocks throughout the economy. In this game, each player ($i = 1, \dots n$) must choose how much (x, y) to hold, subject to a production possibility frontier ($x_i > 0$, $y_i > 0$), such that

$$x_i^2 + \gamma \cdot y_i^2 = b, \tag{1}$$

where $b = 10,000$ and $\gamma = 0.1$, resulting in a marginal rate of transformation $MRT_{x,y} = \frac{x}{\gamma y}$. The holdings decisions are constrained to be efficient. That is, players can only select bundles along the PPF and not within the interior.

After subjects select their desired holdings, each subject experiences an idiosyncratic shock that alters the consumption preference such that only one of the two goods is preferred. Thus, there exist two possible shocks: (i) an x-shock, after which a player prefers to consume only good x and does not derive any utility from consumption of good y or (ii) a y-shock, after which a player prefers to consume only good y and does not derive any utility from consumption of good x. Both shocks occur with equal probability and are specified so that there are two even sides of the market, i.e., for every player with an x-shock, there exists a player with a y-shock. We interpret these preference shocks as liquidity shocks common in banking models (Diamond and Dybvig, 1983).

Since the shock results in a player preferring only one of the two goods, the non-preferred good may be deemed “useless" since no utility can be derived from it. A player holding a useless good can increase her utility by trading the useless good for the preferred good. Hence, following the preference shock, all players will engage in trade because their utility from doing so is strictly greater than zero. The price at which trade takes place is determined by the excess supply (x, y) aggregated over all players. In a given market, players with a y-shock offer $X \equiv \sum_{i=1}^{\frac{n}{2}} x_i$ for trade, while players with a x-shock offer $Y \equiv \sum_{i=1}^{\frac{n}{2}} y_i$ for trade, leading to a price of x, defined as

$$p = \frac{Y}{X}. \tag{2}$$

At price p, each subject maximizes expected utility $J(\cdot)$ according to

$$\max_{x_i > 0, y_i > 0} J(x_i, y_i; p) = \frac{1}{2} u\Big(x_i + \frac{y_i}{p}\Big) + \frac{1}{2} u\Big(p \times x_i + y_i\Big). \tag{3}$$

The first term of equation (3) implies that with probability one-half player i will experience an x-shock and will consume the x_i produced plus the units of x purchased through trade, y_i/p. Similarly, with probability one-half a player will experience a y-shock and will consume the y_i produced plus the units of y purchased through trade, $p \times x_i$.

The optimal solution to the problem specified by equation (3) depends on the market size. In the game, each player can trade either in (i) a bilateral exchange, where only one other trader is present (DM) or (ii) a competitive market (CM), with $n > 2$ traders. Note that the trading environment abstains from complications of a costly search. That is, players can find a trading partner with the opposite preference shock costlessly. Below, we present the solution of the market game, by maximizing the utility function subject to the PPF, in equation (1), and the market clearing condition, equation (2). When players are risk-neutral, and assuming symmetry, we obtain that (see Appendix A)

$$\frac{\partial J/\partial x}{\partial J/\partial y} = MRT, \tag{4}$$

$$\frac{\left(1+\frac{2}{n}\right)+\frac{y}{x}\left(1-\frac{2}{n}\right)}{\frac{x}{y}\left(1-\frac{2}{n}\right)+\left(1+\frac{2}{n}\right)} = \frac{x}{\gamma y}. \tag{5}$$

Using the optimal condition in equation (5) and the PPF in equation (1) we find the optimal holdings of (x^*, y^*). While these expressions are messy in the general case, we can obtain clean expressions for the case where $n = 2$ (DM), and when $n \to \infty$ (CM).

$$(x^*_{DM},\, y^*_{DM},\, p^*_{DM}) = \left(\sqrt{\frac{b\gamma}{(1+\gamma)}},\, \sqrt{\frac{b}{\gamma(1+\gamma)}},\, \frac{1}{\gamma}\right). \tag{6}$$

$$(x^*_{CM},\, y^*_{CM},\, p^*_{CM}) = \left(\sqrt{\frac{b}{2}},\, \sqrt{\frac{b}{2\gamma}},\, \sqrt{\frac{1}{\gamma}}\right). \tag{7}$$

Note that in the DM, the optimal condition from equation (5) becomes $MRT = 1$. That is, traders in the bilateral exchange transform the two goods at the rate of one-to-one. This solution is Pareto optimal because traders do not know the type of shock they will face and with $MRT = 1$ both goods provide the same marginal utility in either state of nature. Interestingly, this solution corresponds to that of a social planner who takes prices into consideration. A risk-neutral social planner knows that when both goods provide the same utility, further reallocation is inefficient.

As the number of traders increases $n \to \infty$, the optimal condition in equation (6) becomes $MRT = p$. This means that a player who is a price-taker will transform between x and y until the marginal rate of transformation is equal to the market price. Such behavior is inefficient because it produces pecuniary externalities. In our environment, one good (x) is scarce, which gives price-takers an incentive to excessively hoard the scarce good until $MRT = p$.

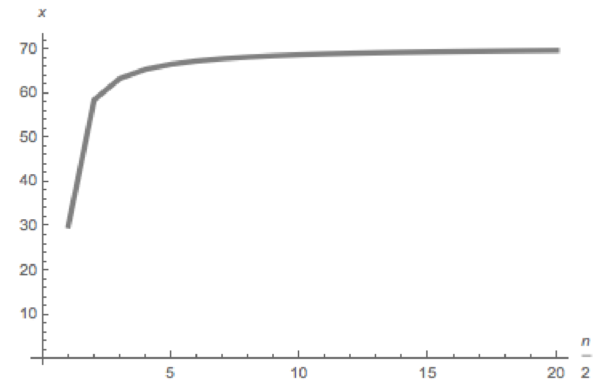

Figure 1: Optimal holding of x as a function of number of market participants n. The x-axis portrays the number of participants in one side of the market $n/2$

Using our parameters values, consider the Pareto solution (DM treatment) where $p = 10$. Acting in individual self-interest, players who take prices as given hoard the scarce good because its pecuniary value of ten is greater than the cost of producing it (equal to one). However, the incentive to hoard will vary with market size. Consider Figure 1, which shows the effect of market size, or $n \in \{2,4,6,\ldots 40\}$ on the optimal choice of x. In our design, we employ $n = 8$ or four traders on each side of the market and find that $x^* = 65.5$, which is close to the Walrasian solution of 70.71, where $n \to \infty$.

In our experiment, the payoff for a CM player is linear in (x,y) and can be specified as,

$$\pi_{CM} = \begin{cases} x + \frac{y}{p} & \text{for x-shock} \\ (x \times p) + y & \text{for y-shock} \end{cases} \tag{8}$$

where p is specified by equation (2).

The payoff for player i in the DM can be also written as a function of the counterparty's choices j

$$\pi_{DM} = \begin{cases} x_i + x_j & \text{for } x\text{-shock} \\ y_i + y_j & \text{for } y\text{-shock} \end{cases} \tag{9}$$

Now, using our parameter values, we write down the following predictions for our experiment,

Prediction 1: *The competitive equilibrium in the CM is such that all subjects choose to produce* $x^*_{CM} = \sqrt{\frac{b}{2}} = 70.71$ *given a price of* $p^*_{CM} = 3.16$.

Recall that $b = 10,000$ and $\gamma = 0.1$. Using these parameter values in equation (7) we obtain Prediction 1.

Prediction 2: *The equilibrium in the DM occurs when all subjects choose to produce* $x^*_{DM} = \sqrt{\frac{b\gamma}{(1+\gamma)}} = 30.15$ *and* $p^*_{DM} = 10$.

Similarly, we obtain Prediction 2 by using our parameter values in equation (6).

Prediction 3: *The production of x in the CM is larger than in the DM*

This prediction is robust to risk-aversion preferences. Even with risk-averse players, production of x in the CM should still be greater than in the DM. For example, if we assume a CRRA utility function

$$u(c) = \frac{c^{1-\rho}}{1-\rho}, \tag{10}$$

then given the following coefficients of risk-aversion, $\rho \in \{.2, .5, 1\}$, we obtain that Prediction 1 still holds while Prediction 2 becomes $x^*_{DM} = \{42.1, 56.3, 60.9\}$. Thus, the difference in production of x between CM and DM ($x^*_{CM} - x^*_{DM}$) remains positive and equal to {28.6, 14.4, 9.8}.

Prediction 4: *The social welfare (mean profit) in DM,* $\pi_{DM} = 331.7$*, is larger than in CM,* $\pi_{CM} = 294.2$*, by 37.5 points.*

Assuming risk neutrality, the equilibrium profit in CM, see equation (8), is $\pi^*_{CM} = \{141.4,\ 446.9\}$ following an x-shock and a y-shock, respectively. Thus, on average a player in the CM receives 294.2 points. Similarly, a player in the DM, see equation (9), gets $\pi^*_{DM} = \{60.3,\ 603\}$ following an x-shock and a y-shock, respectively. Thus, on average a player in the DM receives about 331.7 points. The difference between means is 37.5 or 12.8 percent.

3 Laboratory Procedures

The experiment was conducted at the Learning and Experimental Projects Laboratory (LEEPS) of the University of California, Santa Cruz and the Universidad del Rosario, Colombia. Participants included undergraduate students from all fields and were recruited online via ORSEE (Greiner, 2004). Subjects were assigned to participate in one of the two treatments: CM and DM (between design), with each treatment consisting of 9 practice periods and 50 actual periods.

In total, we conducted 12 sessions, 4 CM and 8 DM, with 8 subjects per session. The higher number of DM sessions can be explained by a higher price variance across decentralized markets. Table 1 presents an overview of all laboratory sessions.

Table 1: Sessions overview

Market (Lab)	Sessions	Participants per session	Profit ($ no show-up fee)
CM (UCSC)	2	8	16.9
CM (Rosario)	2	8	14.7
DM (UCSC)	4	8	13.2
DM (Rosario)	4	8	13.3
Total	12	104	14.5 (mean)

In each session, subjects were presented with a production technology (PPF), depicted in Figure 4. The user-interface, designed using oTree (Chen, et al. 2016), presents a production decision between (x, y), which we called (rues, sennas) for the experiment. Each round in the CM proceeded as follows:

Step 1: Subjects choose how much (x,y) to produce, by clicking on a point along the PPF. To proceed, the subjects then had to confirm their choice by clicking on a button.

Step 2a: After selecting the desired level of (x, y), all subjects experience an idiosyncratic shock, such that a half of the subjects in the session now prefer to consume only x while the other half prefers only y. This also means that subjects will only profit from the preferred good. The idiosyncratic shock is independently drawn each period.

Step 2b: The trading price is then computed by aggregating the relative supply of goods available for trade (the non-preferred goods such that $p = \frac{y}{x}$). Trade is automated, and goods are exchanged according to the market price. Total points, along with other feedback described below, are then presented to every subject.

A player hit with an x-shock will earn $x + y/p$ points while a player hit with a y-shock will earn $x \times p + y$ points. The subjects are informed about the type of shock that they experience using a blue highlight under the appropriate production sub-column (rues, sennas).

Aside from their choices, points earned and prices, we also provide feedback regarding the cost of the last unit produced, i.e. the slope of the PPF or $|MRT_{xy}|$ at that point. Using the cost and the recent market price, we also provide a counterfactual scenario, describing the change in profit if the production of x was increased by one unit.

To give earnings more context, we also include the history of all decisions and outcomes, available in the table to the right of the PPF (see Figure 4). Thus, the decision screen that the player sees at the beginning of each round is continuously updated as information becomes available.

The sessions in the DM treatment follow the same steps described for CM. However, there are a number of important differences. Since the DM is a bilateral exchange, two players out of eight per session are randomly paired every period and thus constitute their

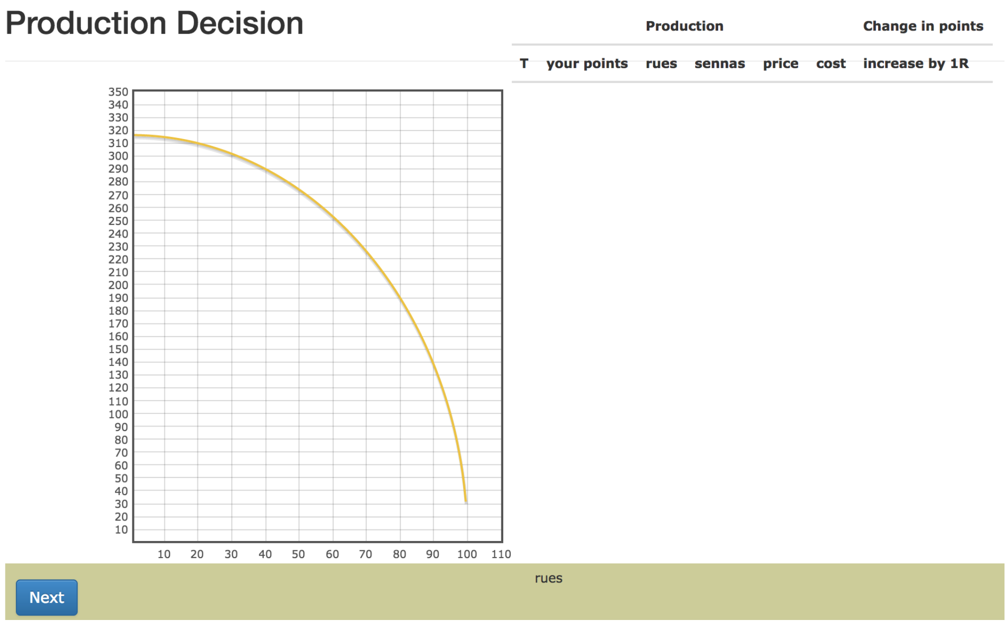

Figure 2: User-Interface CM treatment

own submarket. In each such pair, one player would have experienced an x-shock while the other would have experienced an y-shock. Also, we omit prices in the DM since trade is essentially a barter exchange —players swap their “useless goods". Thus, the feedback provided in each case includes the choice of the counterparty. Lastly, the counterfactual analysis considers the change in points earned if the production of x was increased by one, while keeping the counterparty’s choice constant. That is, the change of points is either one if the player is hit by the x-shock or $-|MRT|$ if the player is hit by the y-shock. The player gives up units of y for producing the additional unit of x.

We include 9 practice periods in order to help the subjects adjust to possible strategic uncertainty. Specifically, in the CM treatment, we draw a random price, that is kept constant for three periods, while in the DM, we draw a random counterparty’s choice. We also provide the outcomes for each shock in the practice rounds. Our instructions (see Appendix B) emphasize that only one random shock will actually occur in the game and that the price is determined by the action of all participants.

The points earned over 50 periods are added and converted to cash at the end of the session at the exchange rate of \$0.7 per 1000 points at UCSC and COL 2100 $= (0.7 \times 3000)$ per 1000 points in Rosario. Each subject also receives a show-up of \$6 at UCSC and \$3.3 $(= 10000/3000)$ in Rosario. The average profit is about \$14.5 excluding the show-up fee. While it may appear that in the DM format the payout is lower than in the CM, when we formally test whether there is difference between the two formats in Table 4, we find that players in the DM format perform slightly better than players in the CM, over time. Higher volatility in the DM appears to suggest a different type of inefficiency in the bilateral exchange that has nothing to do with inefficiencies of the negotiation process. The experimental sessions lasted 1.5 hours on average. In Rosario, the user-interface and instructions were written in Spanish.

4 Results

The key variables of interest in our analyses are subject choices (x, y) and prices which follow the idiosyncratic shocks. We choose to focus only on variable x. The omission of y simplifies our analysis and allows us to concentrate on the impact of market format. Lastly, such approach is not deleterious because the two goods are closely related via the PPF and thus by knowing how x is affected, we can deduce the affect on y. Thus, by studying the price of x, we are also informed about the effect on the price of y.

Table 2: Summary Statistics of x-choices

	All periods		Period 1-25		Period 26-50	
Stat	CM	DM	CM	DM	CM	DM
Mean	67.0	60.4	65.8	61.9	68.1	58.9
SD	22.2	31.3	24.1	31.0	20.1	31.5
Percentiles						
10%	33.5	9.0	29.5	9.5	40.0	8.5
25%	54.5	34.5	51.5	38.9	57.9	31.5
Median	70.5	69.0	70.5	71.0	70.5	64.5
75%	83.5	88.0	83.1	88.1	83.5	87.1
90%	92.5	97.0	94.0	96.5	91.0	97.5

The top panel presents the mean choice of x and the standard deviation, while the bottom panel presents the percentiles using the median choice of x

We begin by our analyses with summary statistics for the mean and median values of x observed in each treatment, CM and DM, across all periods, first half of game (period 1-25) and last half of the game (period 26-50). The mean choice of x suggests that in both treatments the players pick values greater than 60 when we include all periods. Surprisingly, the mean choice of x in the CM is quite close to the predicted equilibrium of 70.71 (67.0 for all periods). However, the mean choice of x in DM is significantly higher than the predicted equilibrium of 30.15 (60.4).

Interestingly, if we look at the sub-sample using periods from the first half of the game (1-25), the mean choice of x is further from either predicted equilibria (lower in CM, 65.8, and higher in DM, 61.9). However, if we use only the periods from the second half of the game only (26-50), the mean choice of x in CM moves closer to the predicted equilibrium value (increases to 68.1), as does the mean choice of x in the the DM (decreases to 58.9).

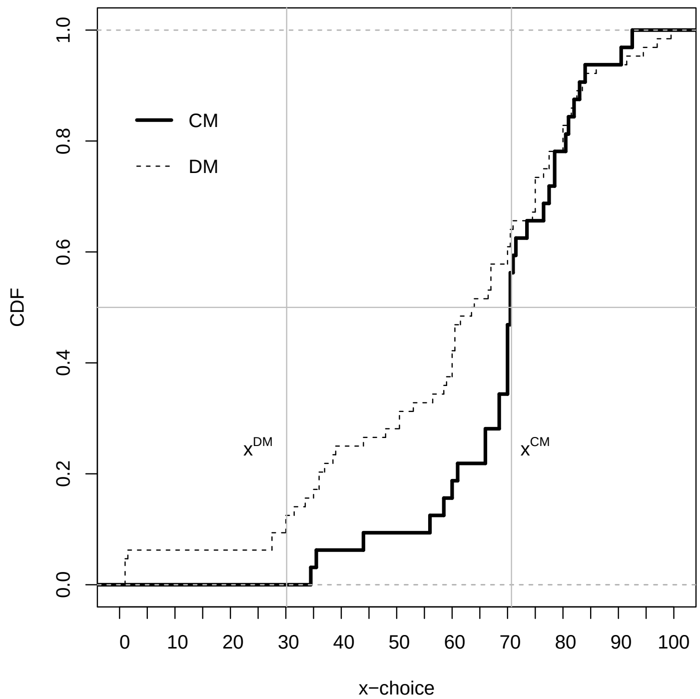

Figure 3: CDF of x-choices by subject in CM and DM. Each observation is the median subject choice for the periods 26-50. The vertical lines represent the predicted equilibrium under DM and CM, respectively.

The changing production decisions across time suggest learning behavior on the part of the subjects. The mean x in CM increases as time goes on, moving closer to 70.71, while the mean x in DM decreases slightly. This behavior in each treatment is consistent with the direction of the equilibrium. Note that we need to be a bit careful when we analyze the difference in behavior across markets. The variance in DM is greater than in CM, which is why we increased the number of DM sessions in our experimental design.

Next, we present a cumulative distribution function (CDF) in Figure 3, using median choice by subject and focusing on the last half of the game. The CDF shows us that in CM, there is a large mass of subjects, who choose equilibrium values of x, which is denoted by a vertical line at $x = 70.71$. This is consistent with previous experimental evidence (Duffy et al. 2011) that shows that as the number of traders increases in a market game, the holdings approach the Walrasian solution. The subjects in DM, on the other hand, fail to consistently play at the predicted DM equilibrium, denoted by a vertical line at $x = 30.15$.

This behavior can be explained by (i) risk aversion and (ii) the relatively small gain in expected profit between formats (12.8 percent). The former explanation states that when the risk parameter $\rho = 0.5$, the mass in the DM should be centered around 56.3 units of x, which is not far from our observed value of 64.5 in the later periods of the game. The second explanation suggests that our results can be interpreted as a lower bound on the efficiency gain due to a small difference in payoffs as noted in Prediction 4. With a greater difference in expected payoff, we would expect a higher mass of participants to choose the optimal level of x, as predicted by theory.

While we see much higher choices of x than predicted in the DM, we also see that for percentiles below 50, there is a clear difference in behavior across treatments. For example the difference between the median choice per subject at 20th percentile is about 25 points.

Table 3: Quantile regressions (Dep. Variable: x - x^*_{CM})

	(I) 10th	(II) 25th	(III) Median	(IV) 75th	(V) 90th
Intercept	-47.34^{***}	-21.47^{***}	-0.21	12.79^{***}	23.9^{***}
	(2.95)	(5.55)	(2.46)	(3.13)	(2.00)
Period	0.41^{***}	0.21^{***}	0.00	0.00	-0.08^{**}
	(0.11)	(0.05)	(0.05)	(0.06)	(0.03)
DM	-13.11^{**}	-8.42	4.77	5.64^{*}	2.42
	(6.63)	(7.10)	(4.02)	(3.24)	(2.24)
Period × DM	-0.46^{***}	-0.43^{***}	-0.27^{***}	-0.06	0.08^{**}
	(0.15)	(0.09)	(0.07)	(0.09)	(0.04)
N	4 800	4 800	4 800	4 800	4 800

The dependent variable is the difference between the choice of x and the predicted equilibrium in the CM (70.71). Standard errors are in parenthesis, clustered at the session level and are computed via bootstrapping.

$^{***}p \leq .01$, $^{**}p \leq .05$, $^{*}p \leq .1$

Next, we perform a more formal Kolmogorov-Smirnov (KS) test to determine whether the distribution of x-choices in CM and DM differ from each other. With the KS statistics = 0.297 and p-value of 0.047 we reject the null hypothesis that the two distribution functions are equal.

Given the difference in the distribution of choices across treatments, it is clear that our regression analysis should focus on the difference of behavior across percentiles. Therefore, we perform quantile regression analysis in which the dependent variable is the difference between the choice of x and the predicted equilibrium in the CM (70.71). The independent variables include: (i) Period, which is a time trend that controls for the learning behavior over the course of the game, (ii) DM, the treatment effect of a DM format which takes the value of one when the exchange is bilateral, and (iii) an interaction term using the time trend (Period) and the treatment effect (DM). The standard errors are clustered at the session level and computed via bootstrapping. Below, we present a summary and a discussion of main results based on regressions presented in Table 3.

Result 1: *The median x in CM is not statistically different from Prediction 1, which states that* $x^*_{CM} = \sqrt{\frac{b}{2}} = 70.71$. *Therefore, we conclude that pecuniary externalities arise in the CM format.*

According to Table 2, the median choice of x in CM is the same in both, first and second half of the game (70.5) and is quite close to the prediction of 70.71. To see whether this is statistically different from the predicted equilibrium, we refer to the regressions presented in Table 3.

In particular, specification (III) which looks at the median quantile, shows that the intercept, which captures the effect of CM treatment, is not statistically different from zero. This means that the subject choice of x and predicted equilibrium x in CM are equal. This conclusion is further strengthened when we look at the coefficient on the time trend (Period), which is also not statistically different from zero, and thus indicates that the subjects do not change behavior with time in the CM treatment.

Result 2: *The median x in the DM is statistically different from CM and is equal to 63. This is above our prediction of* $x^*_{DM} = \sqrt{\frac{b\gamma}{(1+\gamma)}} = 30.15$. *However, about 25 percent of the choices approach (43.63), but do not quite converge, to the predicted equilibrium in the DM. Thus, pecuniary externalities are somewhat mitigated, though not fully eliminated, by the DM format.*

The regression results show that at the 25th percentile, the choice of x is about 43.63 (70.71-21.47+.21*25.5-.43*25.5) in the DM.[7] The choice of x in CM is about 11 units or 26 percent higher than DM.

The median choice of x in the CM (50th percentile) is around the predicted equilibrium. We fail to reject the null that the coefficients on the intercept and the variable Period are statistically equal to zero. However, the interaction term is strongly significant ($p \leq .01$) and therefore the median of DM is about 7 units or about 10 percent smaller than CM.

We formally test whether the median choice in the DM is 30.15 by running an alternative regression in which the dependent variable is the difference between the choice and the predicted equilibrium in DM, and the treatment variable is now CM instead of DM. The median is statistically different than x^*_{DM} ($p \leq .01$).

There is weak evidence of a difference of behavior across treatments for the 75th percentile (see column IV in Table 3). The choice of x in DM is higher than CM by about 6 units, with a significance level of 10 percent. Moreover, there is a minor difference of 2% across treatments at the 90th percentile.

Result 3: *Subjects generally choose higher levels of x in CM than in DM.*

We partially confirm Prediction 3, that the subjects in the CM format tend to select higher levels of x than in the DM. This is supported across all specifications in Table 3, except (IV), on at least 5 percent significance level. Choices in the DM are more extreme, compared to the CM. At lower percentiles, the choice of x is much lower in DM, whereas

[7] We assume that Period is analyzed at 51/2.

at higher percentiles, the choice of x is higher in DM compared to the CM.

Table 4: OLS regressions

	(I)	(II)
	x - x^*_{CM}	$\pi - \pi^*_{CM}$
Intercept	-6.61^{**}	-13.78^{**}
	(2.80)	(5.42)
Period	0.11^{**}	0.03
	(0.03)	(0.07)
DM	-0.61	-10.18
	(3.68)	(6.69)
Period × DM	-0.24^{***}	0.16^{*}
	(0.04)	(0.09)
R^2	0.03	0.01
N	4 800	4 800

Specification (I) uses the difference between x and equilibrium x in CM as a dependent variable, while specification (II) considers the difference in profit between actual and equilibrium profit in CM. Random effects are included at the subject level. Standard errors are in parenthesis, clustered at the session level and are computed via bootstrapping.
$^{***}p \le .01$, $^{**}p \le .05$, $^{*}p \le .1$

Result 4: *The social welfare in CM is slightly below the predicted value and the average surplus in DM is weakly greater than in CM.*

The average profit in CM is slightly below (-13.78 points) the predicted value, as can be seen in specification II of Table 4. This result is consistent with our previous results that some players will overproduce good x, which then negatively affects social welfare (for example see the 75th percentile in Table 3). The average profit in DM is higher by $4 = 0.16 \times 25.5$ points. However, the coefficient on the interaction term is only significant at the 10 percent level. Note that the difference between market formats appears in the interaction variable that considers the treatment effect and the trend. Players in the DM format tend to select lower levels of x the longer they play.

Result 5: *Subjects in the DM treatment learn to behave more optimally with time.*

The learning behavior is also evident when we look at the significance and impact of the interaction term across the first three specifications in Table 3. The coefficient on the interaction term is negative and significant at 1 percent level. To put it in perspective, subjects at the 10th and 25th percentiles in the DM treatment, choose a production level of x that is about 12 points lower as they become more familiar with the environment. In CM, the subjects do the opposite, and increase the production of x, moving them closer to the suggested equilibrium in the CM. Therefore, we can say that over time, the subjects in each treatment learn to choose a more efficient level of production.

5 Discussion

Our experiment was motivated by the idea that an appropriate market format can reduce, if not eliminate, the incidence of pecuniary externalities when markets are incomplete. Our design is based in the theoretical work of He and Kondor (2012, 2016), who illustrate the role of limited commitment and ex-ante production decisions in generating pecuniary externalities. We find that a bilateral exchange is able to slightly mitigate pecuniary externalities, but not fully eliminate them. To the extent of our knowledge, we are among the first to experimentally demonstrate a situation where a bilateral exchange (DM) can be more appropriate than a large competitive market (CM).

Thus, we illustrate that when markets are incomplete, the DM format can lead to a superior outcome compared to the CM. We show that the DM improves social welfare one tenth of the predicted gain. The DM format performs slightly better when we look at the median holding of the scarce good. In this case, traders in the CM over-demand the scarce good by 26 percent relative to the DM. Furthermore, we also show that subjects are able to adjust to their environment over time. The difference in behavior across market formats becomes more pronounced the longer the subjects play the game.

Our results have important policy implications. They suggest that social welfare can be improved if trading institutions are re-designed. In particular, our conclusion suggests that trading should occur through a bilateral exchange or over-the-counter platforms when markets are incomplete. Below we offer other possible explanations for our findings.

First, risk aversion is commonly used to explain departures from the expected optimal profit level. In our setting, it implies holding more than the optimally desired level of the scarce good. In section 2, we stated that with a sufficiently high coefficient of risk-aversion under a CRRA utility function, the difference between the predicted optimal choices across market formats narrows. However, we find evidence that subjects in DM reduce their holdings of the scarce good over time, which increases the difference between formats. Thus, the results suggest that optimal risk neutral behavior can be observed with a large number of iterations, or through ongoing play. Cognitive explanation is also plausible. That is, players might have difficulty with maximizing expected payoffs but they can learn to optimize. This explanation also appears in Bone et al. (2004), in which subjects in groups of two agree on (inefficient) lotteries with equal allocation due to simplicity.

There is experimental evidence on the impact of transaction taxes in complete markets (Huber, et al., 2012). However, we are not aware of any study that seeks to design an appropriate transfer or taxation mechanism to improve the distribution of resources in the economy. Moreover, while one can design contracts to help achieve the socially optimal solution, they may not be fully enforceable (because players may not be truthful about shocks faced). Then, the actions and morals of players become crucial in eliminating or reducing pecuniary externalities. Further laboratory or field work can provide additional evidence on the advantages and the limitations of different policies.

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Appendix A

This appendix provides a detailed solution to the optimization problem in section 2. We can present the Lagrangian problem as

$$\max_{x_i>0, y_i>0} L(x_i, y_i) = \frac{1}{2}u\left(x_i + \frac{y_i}{p}\right) + \frac{1}{2}u\left(p \times x_i + y_i\right) + \lambda\left(b - x_i^2 - \gamma \cdot y_i^2\right) \tag{11}$$

where $\{x_i, y_i\}$ refer to the two consumption goods. The utility is linear and dependent on preference shocks, which occur with probability $\frac{1}{2}$. Next, we determine the FOC with respect to x as

$$\frac{1}{2}\left(1 - \frac{yp_x}{p^2}\right) + \frac{1}{2}\left(p + p_x \cdot x\right) - 2\lambda x = 0. \tag{12}$$

where p is defined by equation (2) and p_x is the partial derivative of p with respect to x. Thus, $p_x = -\frac{Y}{X^2}$, where Y (X) is the aggregate amount of y (x) offered for trade. Assuming symmetry, we can also define $Y = \frac{n}{2} \times y$. Next, we replace p and p_x in equation (12), to obtain

$$\frac{1}{2}\left(1 + \frac{2}{n}\right) + \frac{1}{2}\frac{y}{x}\left(1 - \frac{2}{n}\right) = 2\lambda x. \tag{13}$$

Similarly, we determine the FOC with respect to y as

$$\frac{1}{2}\left(\frac{1}{p} - \frac{yp_y}{p^2}\right) + \frac{1}{2}\left(1 + p_y x\right) - 2\lambda y = 0. \tag{14}$$

where p_y is the partial derivative of p with respect to y, or $p_y = \frac{1}{X} = \frac{2}{nx}$. We then replace p and p_y in equation (14) to obtain

$$\frac{x}{y}\left(1 - \frac{2}{n}\right) + \left(1 + \frac{2}{n}\right) = 2\lambda y. \tag{15}$$

Combining equations (13) and (15), we get the optimal condition (equation 5 in the main text)

$$\frac{\left(1 + \frac{2}{n}\right) + \frac{y}{x}\left(1 - \frac{2}{n}\right)}{\frac{x}{y}\left(1 - \frac{2}{n}\right) + \left(1 + \frac{2}{n}\right)} = \frac{x}{\gamma y}.$$

Appendix B

Instructions CM

Welcome! You are participating in an economics experiment. In this experiment you will play the role of a trader, who can hold two types of goods. If you read these instructions carefully and make appropriate decisions, you may earn between \$6 and \$25, depending on your decisions. You will be immediately paid out in cash at the end of the experiment.

Please turn off all cell phones and other communication devices. During the experiment you are not allowed to communicate with other participants. If you have any questions, the experimenter will be glad to answer them privately. If you do not comply with these instructions, you will be excluded from the experiment and deprived of all payments aside from the minimum payment of \$6 for attending. This experiment will have 9 practice rounds and 50 playing rounds.

THE EXPERIMENT

In this game, 8 players participate in a market. The experiment will consist of two stages every round:

Stage I: Each player is faced with a production decision: how many Rues (R) and Sennas (S) to produce. Your decision screen will show a trade-off in production, which displays all possible combinations of the two goods that you can produce.

Please refer to the screenshot of the game: The quantity of R is on the horizontal axis, while the quantity of S is on the vertical axis.

If you would like to produce more R, then you have to forgo producing some S. At this point, increasing production of R by one more means giving up more than one S. If you would like to produce more S, then you have to forgo producing some R. If you choose to increase S by one, then you have to forgo more than one R.

The trade-off between producing R and S is always changing. If you keep increasing the production of one good, you must give up more and more of another good.

Stage II: After you decide how many R and S to produce, you will find out which of the two goods is profitable. This means that you will earn points from only one type of good in any given round.

Since there are 8 market participants, four randomly selected players will find out that they can only earn points from producing R while the remaining four will find out that they only earn profit from producing S. Thus, you might have a good that you do not get points from.

To increase your earnings, you can trade away the good you do not like. Since you are part of a market, the market marker (the experimenter) will count how many R and S are available for trade and then compute the Price at which you will exchange the unwanted good.

Price of R = Sennas available for trade in the market / Rues available for trade in the market

This means you get X Sennas per 1 Rue.

Points: Your points from each round are computed as follows:

If you get points from Sennas:

Points = Number of Sennas you have + Number of Sennas you buy

You can buy S by selling R. The quantity of S that you can buy is R produced * Price of R

If you get points from Rues:

Points = Number of Rues you have + Number of Rues you buy

You can buy R by selling S. The quantity of R that you can buy is S produced / Price of R.

Interface

The graphical interface is similar to what you will see during the game. You only have to hover your mouse over the line to see the different values of (R, S) and then click to make your choice. When selecting your production, you will have to click on the desired output level and then confirm your choice.

Trading

For a trade to occur, you do not need to enter the amount of R or S that you would like to trade. The market maker will take the useless good from your holdings and trade it for another good.

The points for the good you profit from will be highlighted in blue on your screen. For example, if it turns out that you profit from R, you will see your points for R in blue.

Information available to you:

T: period

Points: Earnings given production choice and shock

Production: Your choice of R and S

Price (of R): how many S you receive for exchanging one R

Cost (of R): how many S you give up to produce the last unit of R

Change in points - increase by 1R: how your points would change if you increased production of R by one unit (or change in profitability)

Change in Points describes how much better (or worse) off you would be if you increase production of R by one unit, holding prices and costs constant.

If you profit from S, your change in profit = p - c or you sell one extra R at price p and that one extra R cost you c Sennas to produce.

If you profit from R, your change in profit = 1 - c/p, where 1 is from producing the additional R, and -c/p is the cost of increasing your production of R.

Your payment

The points you earn from all rounds will be added up, exchanged into dollars and paid to you, along with your show up fee, in cash at the end of the experiment. The exchange rate of points to cash is written on the board.

Practice Rounds

The first 9 rounds will be for practice only. The price of R will be selected randomly and stay the same for three periods. Please note that this will not be the case in the actual game, where the price is determined by the collective action of market participants. The practice rounds are meant to show you how your productions choices affect your payoff. You will see your payoff under two alternative scenarios, where you profit from R and where you profit from S.

Frequently Asked Questions

Q: Do I know which good will be profitable before I choose how many R and S to produce? A: No, you will know what type of good you get points from (like) after you make a decision.

Q: Why is the shape of the production possibilities curved?

A: Because the cost of production is different at each point. It is always changing, which is shown by the changing slope.

Q: How do I trade?

A: The experimenter will act as a market maker. S/he will see how many R and S are available for trade among all 8 players and then determine the price according to the relative amount of each good. The market marker will then take the good you do not like, and give you the good that you do like at the specified price. Your final points are then dependent on the market determined price.

INSTRUCTIONS DM

Welcome! You are participating in an economics experiment. In this experiment you will play the role of a trader, who can hold two types of goods. If you read these instructions carefully and make appropriate decisions, you may earn between \$6 and \$25, depending on your decisions. You will be immediately paid out in cash at the end of the experiment.

Please turn off all cell phones and other communication devices. During the experiment you are not allowed to communicate with other participants. If you have any questions, the experimenter will be glad to answer them privately. If you do not comply with these instructions, you will be excluded from the experiment and deprived of all payments aside from the minimum payment of \$6 for attending. This experiment will have 9 practice rounds and 50 playing rounds.

THE EXPERIMENT

In this game, you will play the role of a producer (stage I) and a trader (stage II).

Stage I: Each player is faced with a production decision: how many Rues (R) and Sennas (S) to produce. Your decision screen will show a trade-off in production, which displays all possible combinations of the two goods that you can produce.

Please refer to the screenshot of the game: The quantity of R is on the horizontal axis, while the quantity of S is on the vertical axis.

If you would like to produce more R, then you have to forgo producing some S. At this point, increasing production of R by one more means giving up more than one S. If you would like to produce more S, then you have to forgo producing some R. If you choose to increase S by one, then you have to forgo more than one R.

The trade-off between producing R and S is always changing. If you keep increasing the production of one good, you must give up more and more of another good.

Stage II: After you decide how many R and S to produce, you will find out which of the two goods is profitable for you. This means that you will earn points from only one type of good in any given round.

Since only one good is profitable for you, you will trade away the good that is not profitable. In this stage, you will be matched with another trader, who has preferences that are the opposite of yours. That is, if Rue is profitable to you, you will be randomly matched with another trader for whom Senna is profitable and you will exchange the goods that you each want to trade away. If Sennas are profitable:

Points = Number of Sennas you have + Number of Sennas you buy

The number of Sennas you buy depends on how much Sennas the trader you are matched with holds. You will trade all your Rues for all of their Sennas.

If Rues are profitable:

Points = Number of Rues you have + Number of Rues you buy

The number of Rues you buy depends on how much Rues the trader you are matched with holds. You will trade all of your Sennas for all of their Rues.

Interface The graphical interface[8] is similar to what you will see during the game. You only have to hover your mouse over the line to see the different values of (R, S) and then click to make your choice. When selecting your production, you will have to click on the desired output level and then confirm your choice.

Figure 4: User-Interface DM treatment

Trading For a trade to occur, you do not need to enter the amount of Rues or Sennas that you would like to trade. Trade will occur automatically once you are matched with another trader and will be based on how much of the nonprofitable good each of you hold. In essence, you each trade away the nonprofitable good in the 2 person submarket.

The points for the good you profit from will be highlighted in blue on your screen. For example, if it turns out that you profit from Rues, you will see your points for Rues in blue.

Information available to you: T: period

Points: Earnings given production choice and profitability shock

Increase 1R: Change in points from increasing production by 1R according to shock

If you profit from R

If you profit from S

[8]We present the graphical interface in the lab projector.

Production: Your choice of production of R and S
Other Trader: Production choice of the trader that you are matched with in that round

Increase 1R describes how much better (or worse) off you would be if you increase production of Rues by one unit.

If you profit from R, your change in profit = +1 , where 1 is from producing the additional R, If you profit from S, your change in profit = - c or how much you gave up to produce the additional R.

Your payment

The points you earn from all rounds will be added up, exchanged into dollars and paid to you, along with your show up fee, in cash at the end of the experiment. The exchange rate of points to cash is written on the board.

Practice Rounds

The first 9 rounds will be for practice only. The choice of the other traders will be selected randomly and will stay the same for three periods. Please note that this will not be the case in the actual game, where you are matched with another trader in the room. The practice rounds are meant to show you how your production choice affects your payoff.

Frequently Asked Questions

Q: Do I know which good will be profitable before I choose how many R and S to produce?
A: No, you will know what type of good you get points from (like) after you make a decision.

Q: Why is the shape of the production possibilities curved? A: Because the cost of production is different at each point. It is always changing, which is shown by the changing slope.

Q: How do I trade? A: You will be randomly matched with a trader who experienced a different profitability shock. That is, if you find out that you profit from R, you will be randomly matched with a player who profits from S. Then you can exchange the goods that do not bring you any profit, for the goods that will make you better off. In this case, you will trade you S for the other player's R. Your final points are then dependent on the amount of R and S amongst the two of you.

References

[1] Allen, F., Carletti, E. and Gale, D., 2009. Interbank market liquidity and central bank intervention. Journal of Monetary Economics, 56(5), pp.639-652.

[2] Asparouhova, E. and Bossaerts, P., 2017. Experiments on percolation of information in dark markets. The Economic Journal, 127(605).

[3] Bone, J., Hey, J. and Suckling, J., 2004. A simple risk-sharing experiment. Journal of Risk and Uncertainty, 28(1), pp. 23–38.

[4] Camera, G., Goldberg, D. and Weiss, A., 2016, Endogenous market formation and monetary trade: an experiment, Mimeo.

[5] Chen, D.L., Schonger, M. and Wickens, C., 2016. oTree–An open-source platform for laboratory, online, and field experiments. Journal of Behavioral and Experimental Finance, 9, pp.88-97.

[6] Cipriani, M., Fostel A. and Houser, D. 2017. Leverage and Asset Prices: An Experiment, Mimeo.

[7] Crockett, S., 2013. Price dynamics in general equilibrium experiments. Journal of Economic Surveys, 27(3), pp.421-438.

[8] Crockett, S., Smith, V.L. and Wilson, B.J., 2009. Exchange and specialisation as a discovery process. The Economic Journal, 119(539), pp.1162-1188

[9] Dávila, E. and Korinek, A., 2017. Pecuniary Externalities in Economies with Financial Frictions. The Review of Economic Studies, p.rdx010.

[10] Davis, D.D., 2017, An Experimental Examination of Interbank Market. Mimeo.

[11] Diamond, D.W. and Dybvig, P.H., 1983. Bank runs, deposit insurance, and liquidity. Journal of political economy, 91(3), pp.401-419.

[12] Duffy, J., 2016. Macroeconomics: A Survey of Laboratory Research. Handbook of Experimental Economics, Volume 2, J.H. Kagel and A.E. Roth (eds.), Princeton University Press, 2016, pp. 1-90.

[13] Duffy, J., Matros, A. and Temzelides, T., 2011. Competitive behavior in market games: Evidence and theory. Journal of Economic Theory, 146(4), pp.1437-1463.

[14] Fostel, A. and Geanakoplos, J., 2008. Leverage cycles and the anxious economy. The American Economic Review, 98(4), pp.1211-1244.

[15] Friedman, D., 1993. The Double Auction Market Institution: A survey. In: Friedman, D., Rust, J. (Eds.), The Double Action Market. Addison-Vesley, pp. 3-25.

[16] Gale, D. and Yorulmazer, T., 2013. Liquidity hoarding. Theoretical Economics, 8(2), pp. 291-324.

[17] Goodfellow, J. and Plott, C.R., 1990. An experimental examination of the simultaneous determination of input prices and output prices. Southern Economic Journal, pp.969-983.

[18] Greiner, B., 2004, An Online Recruitment System for Economic Experiments. In: Kurt Kremer, Volker Macho (Hrsg.): Forschung und wissenschaftliches Rechnen. GWDG Bericht 63. Ges. für Wiss. Datenverarbeitung, Göttingen, pp. 79–93.

[19] Kimbrough, E.O., Smith, V.L. and Wilson, B.J., 2008. Historical Property Rights, Sociality, and the Emergence of Impersonal Exchange in Long-Distance Trade. American Economic Review, 98(3), pp.1009-39.

[20] He, Z. and Kondor, P., 2016. Inefficient investment waves. Econometrica, 84(2), pp.735-780.

[21] He, Z. and Kondor, P., 2012. Inefficient Investment Waves, NBER Working Papers 18217, National Bureau of Economic Research, Inc.

[22] Holmstöm, B. and Tirole, J., 2011. Inside and outside liquidity. MIT press.

[23] Huber, J., Kleinlercher, D. and Kirchler, M., 2012. The impact of a financial transaction tax on stylized facts of price returns-Evidence from the lab. Journal of Economic Dynamics and Control, 36(8), pp.1248-1266.

[24] Keynes, J.M., 1936. The general theory of employment, money and interest. The Collected Writings, 7.

[25] Kugler, T., Neeman, Z. and Vulkan, N., 2006. Markets versus negotiations: An experimental investigation. Games and Economic Behavior, 56(1), pp.121-134.

[26] Lei, V. and C. Noussair, 2002. An Experimental Test of an Optimal Growth Model. The American Economic Review, 92 (3), pp. 549-570.

[27] Lian, P. and Plott, C.R., 1998. General equilibrium, markets, macroeconomics and money in a laboratory experimental environment. Economic Theory, 12(1), pp.21-75.

[28] Magill, M. and Quinzii, M., 2002. Theory of incomplete markets (Vol. 1). MIT press.

[29] Malherbe, F., 2014. Self-Fulfilling Liquidity Dry-Ups. The Journal of Finance, 69(2), pp.947-970.

[30] Noussair, C.N., Plott, C.R. and Riezman, R.G., 1995. An experimental investigation of the patterns of international trade. The American Economic Review, pp.462-491.

[31] Rud, O.A. and Rabanal, J.P., 2016. Evolution of markets: a simulation with centralized, decentralized and posted offer formats. Journal of Evolutionary Economics, pp.1-23.

[32] Shapley, L.S., and M. Shubik (1977): Trade Using one Commodity as a Means of Payment, Journal of Political Economy 85(5), pp. 937-968.