Pecuniary externalities in centralized and decentralized market formats: An experiment

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Abstract

We test in a controlled laboratory environment whether traders in a decentralized market internalize the impact of their actions on market prices better than in a centralized market. In the model, traders choose a production level, constrained by the production possibilities frontier. Subsequently, each trader receives a random shock that makes production of only one type of good profitable. In this environment, pecuniary externalities arise because traders value the scarce good more than is socially optimal and thus do not internalize the impact of their production decisions on market prices. We find that decentralized markets are able to slightly mitigate the extent of pecuniary externalities, but not eliminate them.

Keywords: pecuniary externalities, incomplete markets, general equilibrium, market design, laboratory experiment

JEL codes: D03, D40, D82, G02, G23, G24, C90
1 Introduction

According to Keynes, market imperfections and uncertain future can sometimes result in 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). In general equilibrium (GE) models, we often assume that all possible markets for all possible goods exist for all possible states of nature. When that is not the case, such as when a bond or insurance market is missing, agents are forced to make limited commitments, which often lead to inefficient outcomes (see Keynes, 1936, and Arrow, 1974).

In this paper, we use an experimental approach to study the impact of missing or incomplete markets on pecuniary externalities across two distinct market formats: (i) centralized market (CM) and (ii) decentralized market (DM). Pecuniary externalities generally arise when individuals, acting in self-interest, fail to internalize the impact of their actions on market prices. Empirical evidence (Hoberg and Phillips, 2010) shows that competitive industries fail to internalize the effect of competition on cash flows and stock returns.

Thus, when firms fail to internalize the impact of their actions on market prices, a centralized market format exacerbates investment waves. These waves lead to overinvestment in booms or increasing asset prices, and underinvestment in busts or depressed asset prices (He and Kondor, 2012, 2016, hereafter HK16). Pecuniary externalities associated with collateral constraints that translate in over-borrowing are also common in the macro-financial literature (Lorezoni, 2008). Using a comprehensive framework, Davila and Korinek (2017) characterize two possible types of externalities: (i) distributive and (ii) collateral. Our experiment focuses on the former.

Our findings suggest that decentralized markets are able to slightly mitigate pecuniary externalities, but not eliminate them. The gain of efficiency is only 1/10 of the predicted gain according to theory. However, if we look at the median holding of the scarce good, CM players demand 26 percent above what is optimal, relative to the DM. We also show that subjects are able to adjust to their environment over time. This has important policy implications because, while we are not able to confirm the theoretical prediction of a clearly superior decentralized market, we can say that with time, subjects learn to behave more optimally. Therefore, given a similar environment, a change of format itself is not sufficient to fully resolve the problem of pecuniary externalities.

We propose a game that closely follows the work of HK16 to determine whether market structure can mitigate this problem. HK16 develop a dynamic GE stochastic two period model to show that when firm-level constraints exist (i.e. non-contractible investment opportunities), ex-ante investment is not efficient, thus generating investment waves and

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1 The existence of Arrow-Debreu securities could solve the problem of incomplete markets.
In that game agents are endowed with consumption and capital goods, such that one is scarce relative to the other. Prior to experiencing idiosyncratic shocks, the agents must decide whether to stay at the endowment point or choose another allocation, subject to a kinked production technology. Since production decisions are made prior to knowing the shock type, the ex-ante allocation becomes inefficient. The agents tend to chase the scarce good, thus affecting market prices (i.e. pecuniary externalities).

The inefficiency arises because it is not possible to create a contract for future outcomes, which makes the private value of the scarce good differ from the social value, particularly when markets are competitive. This is further amplified by the ex post resource allocation and rent distribution among agents. We modify this framework and bring it to the laboratory to test whether an alternative market format, a bilateral exchange, can reduce this inefficiency.

Our work is related to literature on static GE models in the lab, which use input and output markets. The results on whether such markets converge to the competitive equilibrium remain mixed. For example, while Goodfellow and Plott (1990) find evidence of convergence, Lian and Plott (1998) and Noussair et al. (1995) find that considerable amount of economic activity occurs outside of the predicted competitive equilibrium. For an overview of the early literature as well as the relatively recent macro experimental literature on dynamic stochastic GE (or DSGE) models see Crockett (2013) and Duffy (2016) for further reference.

Our environment differs in a number of ways with respect to the traditional experimental literature cited above: (i) we include risk and (ii) the market clearing is automated. In our game, the agents do not know the shock type when making a production decision, which adds uncertainty to the environment. However, an uncertain environment has become quite standard in the current experimental DSGE literature.

Furthermore, we automate market clearing by adopting a simple algorithm that computes prices by aggregating excess supply of both goods in the market, instead of using a double-action or similar institution, in order to speed up the trading process. This simplification should not affect the outcome because we know that a CM quickly approaches the competitive equilibrium. For example, see Smith, (1982) and Friedman (1993) for double-auction institutions; and Kugler et al. (2006) and Rud and Rabanal (2016) for a comparison of efficiency between market formats. We still find that quantities, and therefore prices, approach the competitive equilibrium in the CM.

We also omit money in our framework, which means that goods are priced in relative terms. The useless good is traded against the other good that brings utility. This feature allows us to simplify the number of items the agents hold, and work with real variables, which are key to the decision making process. In our experimental design, the
user-interface is graphical (screen shot is provided in Section 3). The subjects only need to choose a point on the production possibility frontier (PPF) to select the bundle of goods that they want to produce. Then, the idiosyncratic shocks determine which type of good are profitable, and finally, the automated market clearing facilitates the exchange of goods between the participants.

To the extent of our knowledge, Bosh-Domenech and Silvestre (1997) are the first to test the impact of incomplete markets on pecuniary externalities in the laboratory. They study whether credit tightness affects economic activity and market prices. 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 quantities and relative prices. In other words, credit constraints lead to incomplete markets, forcing price and quantity to deviate from the competitive equilibrium under complete markets. Cipriani et al. (2017) experimentally test a version of the model introduced by Fostel and Geanakoplos (2008) and find that when an asset also has value as a collateral, there are deviations from the law of one price.

The rest of the paper is organized as follows: section 2 describes the environment that we test, section 3 details the laboratory procedures, section 4 presents the results and lastly, section 5 discusses our main findings. Appendix A includes instructions used in experimental sessions in the LEEPS Lab in UC Santa Cruz.\footnote{The Spanish version of instructions, used at the Universidad del Rosario, can be provided upon request.}

\section{The environment}

Our setup is motivated by the work of He and Kondor (2012, 2016), where ex-ante decisions of firms result in less than optimal outcome following idiosyncratic shocks throughout the economy.

In our environment, each player ($i = 1, \ldots, N$) is faced with a production decision $(x, y)$ that is constrained by the production possibility frontier ($x_i > 0$, $y_i > 0$),

$$x_i^2 + \gamma \cdot y_i^2 = b$$

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

After subjects select their production levels, they experience idiosyncratic shocks that alter the consumption preference toward one good only. Thus, there exist two possible shocks: (i) $x$-shock, when the player prefers to consume only good $x$ and does not derive any utility from consuming good $y$ or (ii) $y$-shock, when the player prefers to consume...
only good y and does not derive any utility from consuming good x. Both shocks occur with equal probability.

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. Therefore, the only way that a player with a useless good can increase his or her utility is by increasing the consumption of the preferred good. This can be accomplished by trading the useless good for the preferred good. Hence, following the preference shocks, all players should want to engage in trade to increase their respective utilities. The price at which trade takes place is determined by the relative holdings of \((x, y)\) aggregated over all players. In a given market, there are \(\frac{X=\sum x_i}{2}\) amount of x to purchase \(\frac{Y=\sum y_i}{2}\) amount of y, leading to the price of x, defined as

\[
p = \frac{Y}{X}.
\]  

The optimal solution to the problem specified by equation (3) depends on the market format. In our game, each player is assigned either to a centralized market (CM) or a decentralized market (DM). The CM can be described as a single competitive market, where all players are price takers. Therefore, in equilibrium, all players in CM take prices as given and the solution is decentralized in nature.\(^3\)

Specifically, the competitive equilibrium is computed by maximizing the utility function, in equation (3), subject to the PPF, in equation (1), and the market clearing condition, equation (2). Under the assumption that players are risk-neutral, we obtain that

\[
\frac{\partial J/\partial x}{\partial J/\partial y} = p = MRT,
\]  

which results in

\[
(x^*_\text{CM}, y^*_\text{CM}, p^*_\text{CM}) = \left( \sqrt{\frac{b}{2}}, \sqrt{\frac{b}{2\gamma}}, \sqrt{\frac{1}{\gamma}} \right).
\]  

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\(^3\)In the literature, the decentralized solution occurs when players act in their own self interest, as opposed to a centralized solution which is provided by a social planner.
The DM, on the other hand, is decentralized in nature, such that there are many smaller markets. In our case, these small markets form bilateral exchanges. This implies that prices are now endogenous in the decision making process.

To determine the equilibrium $x_{DM}^*$, we replace $p$ in equation (3) by $\frac{y_i}{x_i}$ if player $i (\neq j)$ experiences an $x$-shock and by $\frac{y_j}{x_i}$ if player $i$ experiences a $y$-shock. Our optimal condition now becomes

$$\frac{\partial J}{\partial x} = \frac{MRT}{\partial J/\partial y} = 1,$$

which results in

$$(x_{DM}^*, y_{DM}^*, p_{DM}^*) = \left( \sqrt{\frac{b\gamma}{1+\gamma}}, \sqrt{\frac{b}{\gamma(1+\gamma)}}, \frac{1}{\gamma} \right).$$ (7)

It is worth emphasizing that this equilibrium corresponds to the social planner solution in CM. The social planner, just like players in the DM, internalizes the pecuniary externality of a scarce good $x$ (recall that the PPF is biased toward $y$), contrary to the players in CM who move to increase their holdings of $x$.

In our experiment, we impose risk-neutrality in the payoffs. Thus, the profits in CM are

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

where $p$ is computed as in equation (2).

While the profits for player $i$ in DM depends on the choices of the counterparty $j$,

$$\pi_{DM} = \begin{cases} x_i + x_j & \text{for } x\text{-shock} \\ y_i + y_j & \text{for } y\text{-shock} \end{cases}$$ (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 will 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 $\gamma = 0.1$. Replacing the values of these parameters into equation (5) we obtain Prediction 1.

**Prediction 2:** Equilibrium in the DM occurs when all subjects choose to produce $x_{DM}^* =$
\[ \sqrt{\frac{b\gamma}{1+\gamma}} = 30.15 \text{ and } p_{DM}^* = 10. \]

Similarly, we get Prediction 2 by replacing our parameter values in equation (7). Note that in equilibrium, prices in the DM do not equal the MRT, where \( p_{DM}^* = 10 \) and \( MRT_{x,y} = 1. \) A risk-neutral social planner that takes prices into consideration knows that when both goods provide the same utility, further reallocation across the two goods is not optimal. In the decentralized solution of the CM, all players are price-takers. They also realize that the price of \( x \) is equal to 10 because \( x \) is a scarce good. This price is significantly higher than \( MRT_{x,y} \). Acting on individual self-interest, players in CM increase production of \( x \) until \( MRT_{x,y} = p \), which occurs at \( x_{CM}^* = \sqrt{\frac{b}{2}} = 70.71 \).

**Prediction 3:** The production of \( x \) in the CM will be larger than in the DM

This should be true if the players are risk neutral. If the players in our economy are risk-averse, then this could alter our equilibrium predictions in the DM. However, 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, based on the work of Asparouhova et al. (2016) and the citations contained therein,

\[ u(c) = \frac{c^{1-\rho}}{1-\rho}, \quad (10) \]

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, in average a player in CM receives 294.2 points. Similarly, a player in 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 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>
<thead>
<tr>
<th>Market (Lab)</th>
<th>Sessions</th>
<th>Participants per session</th>
<th>Profit ($ no show-up fee)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM (UCSC)</td>
<td>2</td>
<td>8</td>
<td>16.9</td>
</tr>
<tr>
<td>CM (Rosario)</td>
<td>2</td>
<td>8</td>
<td>14.7</td>
</tr>
<tr>
<td>DM (UCSC)</td>
<td>4</td>
<td>8</td>
<td>13.2</td>
</tr>
<tr>
<td>DM (Rosario)</td>
<td>4</td>
<td>8</td>
<td>13.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>12</strong></td>
<td><strong>104</strong></td>
<td><strong>14.5 (mean)</strong></td>
</tr>
</tbody>
</table>

In each session, subjects were presented with a production technology (PPF), depicted in Figure 3. 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 \(x + \frac{y}{p}\) 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 3). Thus, the decision screen that the player sees at the beginning of each round is continuously updated as information becomes available.

![Production Decision](image)

**Figure 1:** User-Interface CM treatment

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 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 A) 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 × 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. The experimental sessions lasted 1.5 hours on average. At 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>
<thead>
<tr>
<th>Stat</th>
<th>All periods</th>
<th>Period 1-25</th>
<th>Period 26-50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>67.0</td>
<td>60.4</td>
<td>65.8</td>
</tr>
<tr>
<td>SD</td>
<td>22.2</td>
<td>31.3</td>
<td>24.1</td>
</tr>
</tbody>
</table>

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), mean choice of \( x \) and CM 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 DM (decreases to 58.9).

![CDF of x-choice](image)

**Figure 2:** 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 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 2, 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 \( x = 70.71 \). We believe that this partially reflects the efficiency of CM as a
trading institution. The subjects in DM, on the other hand, fail to consistently play at the predicted DM equilibrium, denoted by a vertical line at $x = 30.15$.

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>
<thead>
<tr>
<th>Table 3: Quantile regressions (Dep. Variable: $x - x^*_{CM}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(I)</td>
</tr>
<tr>
<td>10th</td>
</tr>
<tr>
<td>Intercept</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Period</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>DM</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Period $\times$ DM</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>N</td>
</tr>
</tbody>
</table>

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.

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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, that states $x^*_{CM} = \sqrt{\frac{b}{2}} = 70.71$. 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 $x_{DM}^* = \sqrt{b\gamma/(1+\gamma)} = 30.15$. However, about 25 percent of the choices approach (43.63), but do not quite converge, to the predicted equilibrium of the DM. Thus, pecuniary externalities are somewhat mitigated, but 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. The choice of $x$ in CM is about 11 units or 26 percent higher.

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

**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.

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4We assume that Period is analyzed at 51/2.
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

The experiment presented in this paper is motivated by the work of He and Kondor, who illustrate the role of limited commitment and ex-ante production decisions in generating pecuniary externalities. Our findings suggest that decentralized markets are able to slightly mitigate pecuniary externalities, but not eliminate them.
Contrary to much of existing literature, we are able to show that there are cases where a DM is not less efficient than a CM. For example, Kugler et al. (2006) conduct an experiment and show that when goods are homogeneous, a CM will always dominate the DM as a market of choice. Similarly, Rud and Rabanal (2016), using an evolutionary approach, show the DM to be the least efficient when compared against a posted offer and a call market formats. In this paper we argue that this is not always the case.

In particular, when markets exhibit externalities or imperfections, a DM may be a better option. Indeed, we show that compared to the CM the DM is able to weakly improve social welfare by about 1.5 percent when markets are incomplete. The gain of efficiency is only 1/10 of the predicted gain according to the theory. DM 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. We also show that subjects are able to adjust to their environment, with time. The difference in behavior across market formats becomes more pronounced the longer the subjects play.

Our results have important policy implications. They suggest that social welfare can be improved if trading institutions for a certain class of assets are re-designed. One could argue that we show small gains relative to the menu costs of altering such trading institutions. However, it is important to highlight that participants in our experiment show learning. Our design consists of only 50 periods, which means that the opportunity to learn is limited. Real market interactions, on the other hand, are often iterated on almost infinite horizon. Therefore, better can be achieved outcomes when players have more time to learn and adjust.

There are other explanations of our findings. First, risk aversion is a common explanation for departures from the expected optimal profit level. In our setting, it implies holding more than optimally desired level of scarce good. The welfare in the CM is below the predicted value which implies that some players over-demand the scarce good. Furthermore, the gains in welfare from switching to the DM are small. Given the CRRA utility function with a sufficiently high coefficient of risk-aversion the difference between market formats is predicted to be small. However, we find evidence that subjects reduce their holdings of the scarce-goods over time, suggesting that the optimal risk neutral behavior can be observed with a greater number of interactions. Cognitive explanation is also plausible. That is, players might have difficulty with maximizing expected payoffs and but they learn to optimize with time.

Future research can shed more light on different approaches to alleviating the (distributive) pecuniary externalities that we study here. 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 social planer 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 to eliminate pecuniary externalities. Laboratory or field experiments can provide additional evidence on the advantages and the limitations of different policies.

6 Acknowledgements

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Appendix A

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\(^5\) 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.

![Production decision graph](image)

**Figure 3:** 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

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\(^5\)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


