Is Money Essential? An Experimental Approach*

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Abstract

Monetary theorists say money is *essential* if more desirable outcomes are incentive feasible when money is available. We develop two models: one where frictions make money essential; one where they do not. Then we study them experimentally. Unlike past work, money can be valued with *finite horizons*, crucial because that is necessary in the lab. Also different from past experiments, we make suggestions about strategies – e.g., "accept money" – that subjects may follow, or not, especially if they are incentive incompatible. Results are largely consistent with theory, with some anomalies that we investigate using measures of social preferences and exit surveys.

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1 Introduction

A central issue in monetary economics is to understand what features of an economy make money a socially useful institution. Based on Hahn (1973), money is said to be *essential* if more desirable outcomes are incentive feasible with it than without it. While money has no such role in traditional, frictionless, general equilibrium theory, there are by now various models that endeavor to take frictions seriously, and in those environments money can be essential (see Lagos et al. 2017 or Rocheteau and Nosal 2017 for surveys). While the formulations differ in detail, it seems clear that three ingredients are needed for essentiality: a double coincidence problem; limited commitment; and imperfect information.

A double coincidence problem means that there are gains from trade that cannot be fully exploited by direct barter. As in Jevons (1875), suppose agents meet bilaterally at random, and are restricted for now to quid pro quo exchange. It may be hard (a coincidence) to meet someone who has what you like, and harder (a double coincidence) to meet someone who has what you like and likes what you have. In many environments, ex ante payoffs are higher if everyone simply produces when asked. If agents can commit, they would agree to always produce when asked, which typically delivers constrained efficiency. Hence, money is not essential.

So, suppose there is no commitment. Then agents may be tempted to renege when asked to produce, rendering the commitment agreement inconsistent with dynamic incentives. Yet that is not enough to make money essential if trading histories are monitored, since then desirable outcomes can potentially be supported as in the repeated game literature: agents who do not produce when asked are punished by having others not produce for them going forward. This is sometimes described as a credit arrangement, with the punishment interpreted as denying future credit to those who fail to honor current obligations.

As Kocherlakota (1998) emphasizes, such punishments must be precluded for money to be essential. Here is a robust result: if it is incentive feasible to implement monetary exchange, and histories are public, it is also incentive feasible to implement the credit arrangement described above, and the latter is always at least as good if not better. Therefore essentiality requires information frictions. There are different ways to capture this (see Gu et al. 2016 and references therein), but a common thread is that it must be hard for society to monitor, communicate or record what happens in pairwise meetings, making it hard to punish bad behavior.

Pursuing the view that essentiality and frictions are of paramount importance, Wallace (2001, 2011) refers to this as the "mechanism design approach" to monetary economics. This is because mechanism design provides a clear distinction between the underlying environment and the rules of the game that map actions into outcomes. Then, once one specifies the set of feasible mechanisms, it is possible to decide whether money is essential in a given environment. Much of the literature on the microfoundations of monetary economics follows this approach.

What may not have been anticipated is that this leads to models of monetary exchange that are in many ways ideally suited for experimental economics. Namely, the theories are tractable enough that their properties are very well understood, and transparent enough that subjects in a lab can comprehend the environment, yet the outcomes can be complex and interesting. In particular, there are generally multiple equilibria, with different properties, due to the self-referential nature of liquidity (what you accept in payment depends on what others accept). A body of work has developed analyzing these models in the lab, although no one has directly investigated essentiality the way we do.[1]

There is another, rather crucial, difference here from virtually all related work: the theory on which we build uses a *finite horizon*. Why is this crucial? Previous papers generally work with infinite horizon models to avoid the following problem:

[1] There are too many papers for an exhaustive literature review, but a few that use models similar in spirit to the ones presented below are: Brown (1996), Duffy and Ochs (1999, 2002) and Duffy (2001), who experiment with the commodity money model in Kiyotaki and Wright (1989); Rietz (2019), Jiang and Zhang (2018) and Ding and Puzzello (2017) who use the fiat money model in Kiyotaki and Wright (1993) or Matsuyama et al. (1993); and Duffy and Puzzello (2014*a*,*b*), who use Lagos and Wright (2005).

if there is a terminal time T at which the game ends, no one at T should sacrifice anything to get money; but then no one at $T-1$ should; and so on. Thus, backward induction implies money is never valued, at least not *fiat* money, defined as a medium of exchange that is "intrinsically worthless and inconvertible" (Wallace 1980). In experiments, this means subjects get no payment for any they have at the end – the "play" money in the lab has no redemption value in "real" dollars.

Now, there is nothing wrong with an infinite horizon in theory, but in practice there is always a terminal time T at which, by rule of law, experiments must end with probability 1. Hence, the games being played in the lab do not actually have monetary equilibria. Experimentalists are aware of this, and there are various attempts to emulate an infinite horizon in the lab. One popular idea is to assume the game ends after each round with some probability, but given the experiments all have a hard stop at time T, that does nothing to get around the induction argument.

This point applies not only to monetary economics, but many other games. As Selten et al. (1997) put it, "Infinite supergames cannot be played in the laboratory. Attempts to approximate the strategic situation of an infinite game by the device of a supposedly fixed stopping probability are unsatisfactory since play cannot continue beyond the maximum time available." Repeated game experiments try to address this in various ways (see Cooper and Kuhn 2014, Fréchette and Yuksel 2017, on general games, and Jiang et al. 2021 on monetary games).

Another attempt to reconcile the infinite horizon in theory and the finite horizon in the lab in monetary experiments is to assign value to money at T based on what payoffs would be if the game were to continue, which is interesting, but treads close to giving up on the fiat nature of fiat currency. Another approach asserts that when the chance of hitting the hard stop is small subjects somehow regard the game as approximately infinite. Without debating the merit of this approximation, it seems problematic that experimenters are trying to learn about monetary equilibria in settings where, strictly speaking, they do not exist.

Given this, we follow earlier work in which some of us were involved (Davis et al. 2020) by using models where monetary equilibria exist even if $T < \infty$, and, in fact, we use models with $T = 2$ periods. The insight that monetary equilibria are possible in finite environments is not new: our approach is closely related to the discussion of money in Kovenock and Vries (2002), somewhat related to the discussion of bubbles in Allen et al. (1993) or Allen and Gorton (1993), and ultimately related to discussions like Samuelson (1987) of how lack of common knowledge about the final period ameliorates end-game effects. What is novel is to bring this into the lab.[2]

Details are below, but here is the idea. Suppose there are only two trading opportunities and agents do not know if they are in the first or second. Then agents may accept money in the second, even though there are no future trading opportunities, because are uncertain whether it is the first or second opportunity. Even when all players understand the horizon is finite, this uncertainty implies that accepting money can be consistent with equilibrium. Moreover, since the monetary equilibrium yields higher payoffs than the best outcome without money, it is essential.

Yet questions arise. One is, do agents actually use money when there is a monetary equilibrium? Theory says they may or may not, because there always coexists a nonmonetary equilibrium. Another is, do they accept money when there is no monetary equilibrium? Theory says they should not, but they might. If money is accepted when that is not an equilibrium, why? Is it due to altruism or some kind of social preferences? Another difference from past work is that we use exist surveys and other techniques to address some of these questions.

Yes another difference is that we sometimes offer subjects *suggestions* about strategies. The idea is that the multiplicity of equilibria leads to a coordination problem: agents may settle on the inferior nonmonetary equilibrium even if monetary equilibrium exists. Hence, we ask if a mediator can ameliorate the problem,

[2] To be clear, Davis et al. (2020) take a finite horizon model into the lab, but there are many differences: (i) We adopt a mechanism design perspective. (ii) We study whether recommendations (see below) affect equilibrium selection. (iii) We elicit information about social preferences and ask if anomalous behavior can be understood in terms of altruism, inequality aversion etc. (iv) We use exit surveys to uncover subjects' motivation. (v) We made design changes to minimize potential repeated game effects.

by making suggestions, consistent with an interpretation of equilibria going back to Nash (1950).

Suggestions are typically frowned upon in experimental work: "the researcher must be careful to avoid demand effects – avoid suggesting the desired results to the subjects either explicitly or implicitly" (Croson 2002). Yet suggestions seems appropriate and consistent with mechanism design methods. A suggestion can be something like "accept money" (this is made precise later), but it must be emphasized that subjects need not follow it, and if monetary equilibrium does not exist they ought not follow it. Unlike most related papers, our goal is *not* to see if subjects can learn to use money over time, but to ask whether money is helpful for supporting efficient outcomes, with recommendations used as a device for coordinating beliefs.

Our findings indicate that suggestions can help, but a suggestion to accept money is more likely to be followed if it is consistent with equilibrium. Another finding is that agents can be rather sophisticated, trying to make inferences about future opportunities to spend money by the timing of offers to accept money. All of this is fairly supportive of the idea that individuals, or at least a good number of them, behave in ways consistent with theory, and that money is useful in supporting good outcomes in environments with trading frictions.

2 Theory

There are three agents and two events called (pairwise) meetings. In the first meeting one agent is the consumer and other the producer. Consistent with the relevant literature, we think of these two agents and their roles, consumer or producer, as determined randomly by nature. Agents know their roles as producer or consumer in meetings. Let us label the consumer Player 1 and the consumer Player 2, and the one not in the meeting Player 3. In this meeting nature may or may not endow Player 1 with money, an intrinsically useless token that is storable and transferable but indivisible. Actions in meetings are described below. After actions in the first meeting, there is a meeting between Players 2 and 3, where 2 is the consumer and 3 the producer. After actions in the second meeting the game ends.

Possible actions in first meeting are described as follows:

- Player 1 chooses from: make no offer; ask for the good for free; ask for the good in exchange for money *if 1 has money* (in principle 1 could also offer money for nothing but we ignore that).
- If no offer is made Player 1 and 2 part ways.
- If an offer is made Player 2 chooses from: accept, at which point the trade is executed and they part ways; reject, at which point they part ways.

After Players 1 and 2 part ways the meeting between Players 2 and 3 occurs. The possible actions are the same, although note that in the second meeting, whether Player 2 has money depends on what happens in the first meeting and not on nature, and that after Players 2 and 3 part ways the game is over. In each meeting, if the producer transfers the good to the consumer the former gets disutility $-c$ and the latter gets utility u, where $u > c > 0$. Given that the meeting technology is a primitive of the environment, but that agents' roles as Player 1, 2, or 3 are randomly assigned by nature, the efficient arrangement is for producers to always produce, similar to standard infinite horizon models.[3]

Let us first discuss what happens when nature endows Player 1 with money. As mentioned in the introduction we consider two scenarios: in Model 1, producers in meetings know if it is the first or second meeting; in Model 2 they do not (effectively this means producers do not know if they are Player 2 or Player 3). Model 1 has a unique equilibrium and it entails autarky – i.e., no trade. The argument is simple: in the second meeting Player 3 will not bear cost c to produce unless Player 2 gives something of value in exchange, but the only thing 2 could have is money, and that

[3] The setup has a double coincidence problem. If agents met trilaterally, they could agree on this: let them be randomly assigned labels 1, 2 and 3, then 2 produces for 1 and 3 produces for 2. The ex ante payoff is $\frac{2}{3}(u-c)$. The problem is that they meet sequentially in pairs.

is worth nothing since the game is over after this meeting. Given this, in the first meeting Player 2 will not produce by the same reasoning. Hence, there is no trade.

Some comments are in order. First, this argument does not even require subgame perfection, but holds using Nash equilibrium or iterated elimination of strictly dominated strategies as a solution concept. Also, the result easily extends to any finite T, with many agents, whether or not we adopt random terminations at $t < T$; here we use $T = 2$ because it is the shortest interesting horizon, and that minimizes effects like agents regarding big $T < \infty$ as somehow (irrationally) approximating $T = \infty$. Also, as should be clear, the autarky outcome is the same as the unique equilibrium in Model 1 if there is no money.

Now consider Model 2. If there is no money the unique equilibrium is again autarky. If Player 1 is endowed with money autarky is still an equilibrium: if others do not produce for money it is a best response to follow suit. However, there can be a monetary equilibrium with production in exchange for money in both meetings. To confirm this, suppose a producer does not know if it is the first or second meeting, and assigns the correct probability to each, 1/2. The the expected payoff to producing is

$$\frac{1}{2}(-c+u)+\frac{1}{2}(-c),$$

which is strictly positive if $u > 2c$. in this case producing for money is a strict best response, provided others do the same. Monetary equilibrium exists.

Also, money is essential. Without it, the unique equilibrium is autarky with payoff 0, while the monetary equilibrium gives positive expected payoffs to everyone. Although the realized payoff to 3 is $-c < 0$ after getting stuck with the money, we still say this outcome is desirable because ex ante payoffs are higher, or, amounting to the same thing, because average payoffs are higher if the game is played multiple times (here readers may notice a resemblance to work on optimal opacity, e.g., Andolfatto et al. 2014 or Dang et al. 2017).

There is also a mixed strategy equilibrium. Let p be the producer's probability of accepting an offer to trade for money. Now $p \in (0,1)$ is best response if the producer is indifferent, $\frac{1}{2}(-c+pu)+\frac{1}{2}(-c)=0$. Hence there is an equilibrium where goods trade for money with probability $p=2c/u$ in each meeting. Some realizations will see production in the first meeting but not the second.[4]

An extension of the model may also be relevant. Although in theory Model 2 has Players 2 and 3 unable to distinguish between the first and second meeting, if the game is played in real time, inferences can be made. In particular, agents might use waiting time as a signal determining the likelihood of being in meeting 1, which seemed to happen in the experiments. Hence, we consider a setup where such inference is possible and show monetary equilibrium still exists if waiting time is a sufficiently noisy signal.

Let agents distinguish between $\{t_E, t_M, t_L\}$, indicating early, middle and late in the game (this can be extended to richer sets of signals at a cost in terms of tractability). Assume the first meeting can occur at t_E or t_M and the second can occur at t_M or t_L, creating a signal-extraction problem: agents cannot tell meeting 1 from meeting 2 when $t=t_M$. The probability distribution over $\{t_E, t_M, t_L\}$ conditional of being in the first meeting is

$$\Pr(t_E|\text{meeting 1}) = 1-q,\ \Pr(t_M|\text{meeting 1}) = q,\ \Pr(t_L|\text{meeting 1}) = 0,$$

where q is an objective probability that is part of the environment. In the second meeting

$$\Pr(t_E|\text{meeting 2}) = 0,\ \Pr(t_M|\text{meeting 2}) = r,\ \Pr(t_L|\text{meeting 2}) = 1-r,$$

where q is also an objective probability.

[4] Shevchenko and Wright (2004) point out that there are robustness issues with the mixed strategy equilibrium: consider the deviation where the consumer offers a lottery, where the producer gets money and the consumer gets the good with some probability. This deviation not directly applicable to our experiments, however, as there is no way to propose a lottery. There can also exist sunspot equilibria: if players had access to some intrinsically irrelevant, commonly observed random variable, called a sunspot, they could potentially condition strategies on it. Hence, trade can occur for some realizations and not others. In the experiments this seems unlikely, however, mainly because subjects do not see any such random variable.

If the meeting occurs early, it is known to be meeting 1. If the meeting occurs late, it is known to be meeting 2. However, the information content in $t = t_M$ depends on the acceptance strategy, because if players do not accept money a money offer reveals that it is meeting 1. In contrast, assuming that a monetary equilibrium exists in which money is accepted for sure at $t \in \{t_E, t_M\}$, Bayes rule implies

$$\Pr(\text{meeting } 1|t_M) = \frac{q}{q+r}.$$

If the player produces in the first meeting in exchange for money, the next producer will not produce if that player can detect that it is meeting 2. The probability of that is r, and the expected payoff from accepting at $t = t_M$ is

$$\frac{qr}{q+r}(u-c) + \left(1 - \frac{qr}{q+r}\right)(-c) = \frac{qr}{q+r}u - c.$$

Acceptance at t_E gives $ru - c$, so if players are best responding by accepting money at t_M they will optimally accept offers at t_E. Hence, there is a pure strategy equilibrium where players produce in exchange for money, except when they know it is the last meeting, provided that

$$\frac{qr}{q+r}u - c \geq 0.$$

Note that production rates will be higher at meeting 1 than in meeting 2. Also note that $q = r = 1$ is Model 2 and $q = r = 0$ is Model 1, so this extension spans the two baseline models. Finally, note that there is also a mixed equilibrium whenever $qru/(q+r) > c$, where acceptances are probabilistic at t_M.

3 Experimental Design

Each experimental session was conducted as follows. First, subjects participated in a series of rounds that parameterize the models in Section 2. Then they were given an exit survey asking questions about their considerations in playing the game, plus a few demographic questions. Finally, they participated in a series of experiments designed to elicit information about social preferences. The reason for the last part is this: predictions in Section 2 are based on agents that only care about their own payoffs, which need not be a good description of our participants. Hence, they play a generalized dictator game that provides evidence of that. The Online Appendix has details on the experiments and surveys: https://www.sultanum.com/research.html.

In total we ran four monetary treatments and one treatment without money. The equilibrium allocation without money is the same for the two models, so we opted to run experiments without money in Model 2 only. For the treatments with money, two are based on Model 1, where monetary equilibrium does not exist, and two are based on Model 2, where monetary equilibrium exists. For each, we ran treatments where it was left up to the subjects to find (or not) equilibrium, plus treatments where we act as a mediator by suggesting strategies. These suggestions were equilibrium strategies (best responses) in Model 2, but not Model 1.

Part 1 of every treatment consisted of 15 rounds, where in each round a game from Section 2 is played once. As is standard in experimental economics, participants played the games multiple times to gain experience, learn the incentives, and possibly coordinate beliefs. To avoid participants approaching the 15 rounds as a repeated game, we randomly assigned subjects to groups of three in each round. While some subjects interacted more than once, they were anonymous, and the number of participants seems large enough that reputation-building effects should minimal.

At the beginning of the Model 1 experiments, each participant was randomly selected into the role of Player 1, 2, or 3 with equal probability. These roles were then fixed for all 15 rounds, implying that in each session there were N players in each role. Then, in each round N groups were formed with one player randomly selected from the sets of players 1, 2, and 3.

In each round of the monetary treatments Player 1 was endowed with a token and could in meeting 1 offer it to Player 2 in exchange for production. Then Player 2 accepted or rejected. Then in meeting 2, if the token was acquired, Player 2 could choose whether to offer it to Player 3 in exchange for production. Then Player 3 accepted or rejected. Player 3 had to give up the token (for nothing) if it was acquired. This completed the round, and the players were then randomly assigned to new groups of 3, except in round 15, which completed first part of the session.

Model 2 treatments started with selecting participants to be Player 1 or not Player 1. If Player 1, which happened with probability 1/3, the subject stayed in that role for all 15 rounds. The other subjects were randomly assigned as Player 2 or 3 with equal probability in each round, and were not informed about that until after production.

As in Model 1, Player 1 was endowed with a token and could offer it in exchange for production. After accepting or rejecting, the recipient was informed about their role, Player 2 or 3, in that round. If the token was accepted by a subject in their role as Player 2, it could be used in the next meeting with Player 3. Importantly, the participant in the role of Player 3 was uninformed whether they were 3 meeting 2 or 2 meeting 1. After accepting or rejecting, Player 3 learned their role and payoffs (points) were tallied. Then the players were randomly assigned to new groups of 3, and those not previously assigned as Player 1 were randomly assigned new roles as 2 or 3, except in round 15.

The instructions for the treatments with strategy suggestions, Model 1-S and Model 2-S, were the same except that the instructions and decision screens included the following language:

> **A suggestion**: *Each player in a group may consider making the following choices:*
>
> 1. *Whenever you have the token, transfer it to the next player (if there is one).*
>
> 2. *Produce ONLY if you are offered the token.*
>
> *This is simply a suggestion. Feel free to follow it or not.*

The suggestion recommends following the monetary strategy of always offering the token if in possession of it, and always producing in exchange for it. The treatments with this non-binding recommendation were designed with two purposes in mind. First, we can study whether providing the suggestion facilitates coordination on the monetary equilibrium in Model 2. Second, since the monetary strategy can be supported as an equilibrium in Model 2 but not Model 1, introducing the suggestion in Model 1 allows us to determine the strength of any possible *demand effects* and whether subjects follow the suggestion indiscriminately, regardless of whether it is consistent with equilibrium.[5]

Model 1 and Model 2 treatments were designed to test whether fiat money is more likely to increase production and welfare when its usage is an equilibrium outcome (Model 2), compared to when it is not (Model 1). Everything else in the design keeps other differences at a minimum.

In all treatments, subjects were endowed with 3 points, and could earn additional points from playing the games. Specifically, they earned $u = 3$ points from consumption and lost $c = 1$ point from production. Three out of the 15 rounds of each session were randomly selected for payment.[6] Points were converted into dollars a the rate 1 point equals 2 dollars. Tokens are not converted into dollars and subjects were explicitly told "The token does not yield points directly and cannot be transferred from one game to another."

After this, subjects were asked to complete an exit survey tailored to the position they were assigned in the experiment. This survey was designed to better understand considerations that played a role in their decisions. After this, subjects completed a demographic survey on gender, age, English proficiency and field of study.

Then subjects moved on to the second part of the experiment, where they played a series of generalized dictator games. This part of the experiment provides a measure of their social value orientation (SVO) following Murphy et al. (2011). This measure is meant to control for differences between theoretical and real-world pref-

[5] In each treatment, the instructions for the first part were read aloud by the experimenter and followed by a questionnaire to test understanding of the environment, including payoff determination, position assignment, timing and grouping.

[6] In each game the lowest possible score is -1, when the subject produces but does not consume. Since three games were randomly selected for payment, the endowment of 3 points guaranteed that no player incurred losses in this part of the experiment.

erences that might be characterized by altruism or inequality aversion.

We used the computerized module developed by Crosetto et al. (2019) for implementation on zTree and oTree. It consists of a series of 15 generalized dictator games where each subject chooses as a sender how to allocate payoffs to sender and receiver (the other subject). We used the ring matching protocol so that each subject functions as both a sender and a receiver. From the first six (primary) games, one can derive each subject's SVO index as the average allocations for the receiver over the average allocations for the sender. A high SVO index represents a more prosocial or altruistic social value orientation.

The nine secondary games can further separate efficiency motives from equality motives (as the two motives are maximized simultaneously in the primary games). From the secondary games one can calculate the inequality aversion score. After every subject finished the 15 SVO games, one game of each subject is randomly selected to determine each subject's payoff as a sender and as a receiver. The points in this part of the experiment were converted to cash at the rate 100pts = \$3.

The experiments were conducted in 2020 and 2021 at the IELAB at Indiana University or online with remote participation. The subject pool consisted of Indiana University students recruited via the Online Recruitment System for Economic Experiments ORSEE (Greiner 2015). The experiments conducted face-to-face in the IELAB were programmed using zTree (Fischbacher 2007), while the online experiments were programmed using oTree (Chen et al. 2016), keeping the decision screens and procedures as close as possible. In the online sessions, subjects were admitted into a "zoom room" where they received links to the experiment. Subjects could only use the private chat function to communicate with the experimenter. In face-to-face laboratory sessions, subjects could raise their hand and the experimenter would address the subject privately.

We ran four sessions in each monetary treatment with the exception of Model 1, where we conducted six sessions, and we conducted two sessions of Model 2 without money.[7] The two sessions without money were conducted to further validate the essentiality results from other treatments.

Table 1: Experimental Design

Treatment	Suggestion	Sessions	Subjects
Model 1	No	6	72
Model 2	No	4	51
Model 1-S	Yes	4	48
Model 2-S	Yes	4	48
Model 2-No Money	No	2	18

We used an across-subject design and no subject participated in more than one session. For each session 9 to 15 subjects were recruited, for a total of 237 subjects. The number of subjects per session varied depending on the show-up rate. Subjects were paid for the first and second part of the experiment, and earned an average of approximately $19 for between 45 and 60 minutes. Table 1 summarizes the design and session characteristics.

We formulate the following hypotheses based on theoretical predictions and previous experimental evidence. First of all we note that in both Model 1 as well as in Model 2, the unique equilibrium is autarkic when there is no money. While this is not the main focus on the paper we therefore postulate:[8]

Hypothesis 1. *In Model 2, production is higher with money than without.*

Theory predicts that autarky is the unique equilibrium in Model 1, while autarky and monetary exchange are equilibria in Model 2. Past experimental evidence indicates that in coordination games subjects tend to gravitate toward more efficient outcomes. Based on these observations, we formulate the following hypotheses:

[7]For the record, four of the six sessions for Model 1 were conducted face-to-face in 2020 prior to the COVID-19 pandemic, after which we moved the remaining sessions online. In the Online Appendix, we provide a comparison between the online and in-person sessions.

[8]Note that previous experiments find higher production with money even in models that do not, stricly speaking, have monetary equilibria. Also, some experiments indicate that money can be useful even if not essential. Duffy and Puzzello (2014) and Camera and Casari (2014) study economies where credit (as described in the Introuction) is feasible, so money is not technically esstential, but it still seems to help deliver superior outcomes.

Hypothesis 2. *Production is higher in Model 2 than Model 1.*

Hypothesis 3. *Production is enhanced by the suggestion in Model 2, not Model 1.*

4 Results

In this Section we do several things. First we test whether money is essential in Model 2, then we test whether production is higher in model 2 than Model 1. The we check whether making a suggestion leads to higher production in Model 2, where it could help coordinate on the better equilibrium, and in Model 1, where it should not.

4.1 Money

We first document that money leads to significant increases in production. As seen in Figure 1, production in Model 2 with money converges towards approximately 60%. When there is no money it is about 20% towards the end. While this is higher than theory predicts, note that results in Model 2 without money look very similar to those in Model 1 with money, which is a model with the same equilibrium allocation.

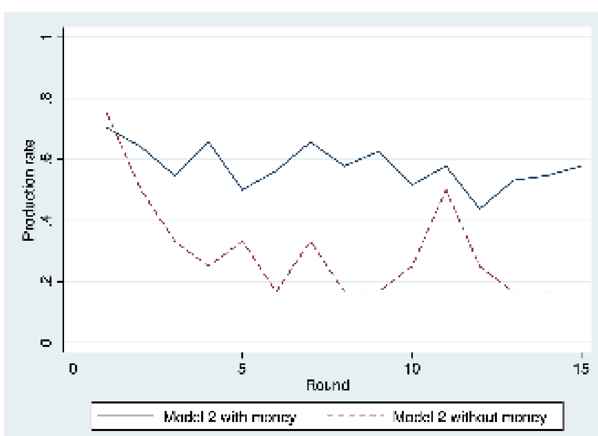

Figure 1: Production Rates with and Without Money

As another way to see that money has significant effects, consider Table 2. Effects are statistically significant overall, in early, and later in rounds.

Table 2: Production Averages for Model 2 with and without Money

	M_2 without money	M_2 with money	Difference (t-test)	# of Observations
All Rounds	0.3000***	0.5771***	0.2771**	1,140
	(0.1222)	(0.0287)	(0.0955)	
Rounds 1–3	0.5278***	0.6302***	0.1025**	228
	(0.0278)	(0.0350)	(0.0404)	
Rounds 4–9	0.2361***	0.5964***	0.3602***	456
	(0.1250)	(0.0301)	(0.0979)	
Rounds 10–15	0.2500***	0.5312***	0.2812*	456
	(0.1667)	(0.0341)	(0.1288)	

Note: Standard errors in parentheses are clustered at the session level.

4.2 Model 1 vs Model 2

Theory predicts that when agents know their position, as in Model 1, there is only the autarkic equilibrium. However, if they do not, as in Model 2, then there is a monetary equilibrium. As stated in Hypothesis 2, production should be higher in Model 2 than Model 1. Our first finding supports this.

Finding 1 *Comparing production across models, production in Model 2 is 34% above Model 1;*

Table 3: Production Averages by Model

	M_1	M_2	Difference (t-test)	# of Obs.
All Rounds	0.2400***	0.5771***	0.3371***	2,160
	(0.0299)	(0.0287)	(0.0402)	
Rounds 1–3	0.3750***	0.6302***	0.2552***	432
	(0.0578)	(0.0350)	(0.0659)	
Rounds 4–9	0.2187***	0.5964***	0.3776***	864
	(0.0350)	(0.0301)	(0.0342)	
Rounds 10–15	0.1937***	0.5312***	0.3437***	*864
	(0.0268)	(0.0341)	(0.0420)	

Note: Standard errors in parentheses are clustered at the session level.

Figure 2 shows production by round in Model 1 and 2 over all meetings. There is a large difference in production between models and it persists across all rounds. Production tends to decrease initially before stabilizing, consistent with the idea that subjects are learning, perhaps about how the experiment works in general, or about what others are doing. Overall production is roughly 24% in Model 1, but it starts close to 50% and then declines to 20%. While theory suggests that there should be no production in these treatments, based on other experiments we expected that some production would occur, particularly in early rounds, when subjects are learning. Of course, altruism or plain misunderstanding could also lead some subjects to produce. Based on experience it would have been surprising if there were no production in Model 1.

Overall production in Model 2 is higher, roughly 60%, starting at 70% and declining slightly. Because of the multiplicity of equilibria there is no point prediction from economic theory. In fact, the rate of production is remarkably close to the production probability in the mixed strategy equilibrium, which is 2/3 for the parameters in the experiment. However, it may be difficult to imagine agents honing in on a mixed-strategy equilibrium, and to test whether that is actually happening, so we do not want to push this too far.

Table 3 reports average production for Model 1 and 2 and t-test results on treatment differences (see Table 5 for average production by session). We look at the full sample, plus we separate early rounds 1-3 from later rounds. As shown in Table 3, production in Model 2 is significantly higher than Model 1, regardless of how we segment the data. These results are confirmed by a two-sided Wilcoxon rank-sum test with details that can be found in the Online Appendix mentioned above.

The difference between production in Models 1 and 2 is consistent with theory: production is much higher when monetary exchange is an equilibrium. Non-zero production in Model 1 goes against the theoretical prediction, as mentoined above, and we will discuss this more below. We will also discuss whether results from the exit surveys provide insight as to why subjects produce when it is not a best response, as is particularly puzzling when Player 3 produces.

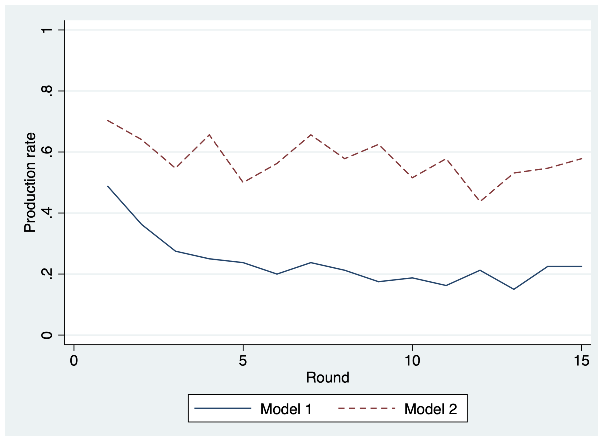

Figure 2: Production Rate by Model

4.3 Suggestions

Recommending that subjects produce for money in Model 1, where the only equilibrium is autarky should not have an impact because it is inconsistent with equilibrium to follow the suggestion. In contrast, when a monetary equilibrium exists it seems plausible that recommending that subjects play in accordance with that equilibrium could help coordination. It is true that participants may just ignore the suggestion if they believe that others will ignore it, but should they believe others will follow it, the suggestion is a strict best response in Model 2.

In order to disentangle different effects, we run the following regression:

$$P = \beta_0 + \beta_1 \times M_2 + \beta_2 \times S \times M_2 + \beta_3 \times S \times M_1 + C.$$

Here P denotes production, M_1 and M_2 are dummies identifying Models 1 and 2, S is a dummy for whether we suggest that subjects produce for money, and C are controls. We control for the meeting, which is 1 or 2, and the round, which goes from 1–15. We also restrict our sample to production decisions in meetings where a subject was offered money, and found that the results are robust to this and other changes in specification.[9]

Table 4: Number of Observations of Monetary Treatments

	Meetings	Meeting 1	Meeting 2
Total	2,160	1,080	1,080
With Production	842	574	268
With Money Offer	1,708	1,047	661

We find evidence in support of Hypothesis 3.

Finding 2 *Comparing production with and without suggestions: the suggestion significantly increases production in Model 1 only in early rounds; the suggestion significantly increases production in Model 2 in early, middle and late rounds.*

Table 5: Impact of Strategy Suggestions

	M_2	$S \times M_1$	$S \times M_2$	# of Obs.
All Rounds	0.3124***	0.0998	0.0941**	1,708
	(0.0366)	(0.0634)	(0.0346)	
Rounds 1–3	0.3136***	0.2266**	0.0419	365
	(0.0826)	(0.0881)	(0.0679)	
Rounds 4–9	0.3476***	0.0786	0.1075***	668
	(0.0387)	(0.0416)	(0.0377)	
Rounds 4–15	0.3137***	0.0600	0.1067***	1,343
	(0.0424)	(0.0738)	(0.0320)	

Note: Standard errors in parentheses are clustered at the session level.

[9] It is worth mentioning that subjects almost always offer the token when they have it. In Model 1 the token offer rates are 96% and 97% in meetings 1 and 2; and in Model 2 they are 98% and 96% in meetings 1 and 2.

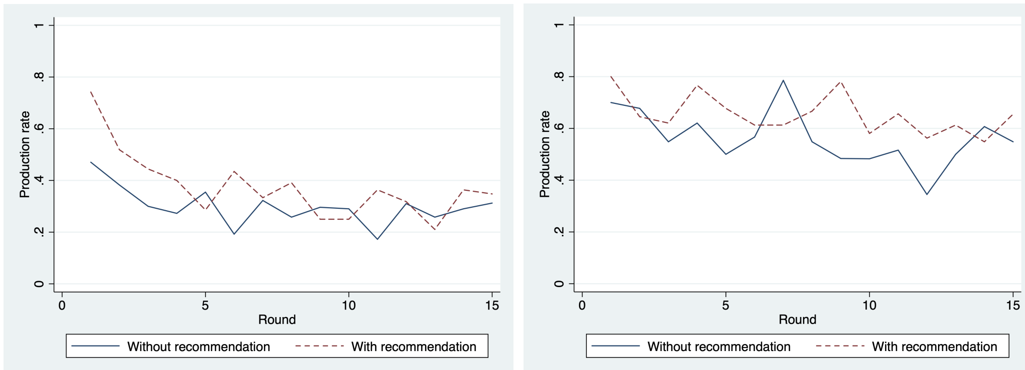

Figure 3: Production by Model and Suggestion

Table 5 and Figure 3 provide support for Finding 2 (see also the Online Appendix where we report robustness checks). Figure 3 depicts average production by round for different treatments. The panel on the left plots production with and without suggestion for Model 1, while the one on the right plots it for Model 2. The overall conclusion from Figure 3 and Table 5 is that the suggestion seems to improve coordination when consistent with equilibrium, and is largely ignored otherwise. This indicates that the increased production in Model 2 has to do with improved coordination, as opposed to, say, a desire by the participants to please the experimenter.

Specifically, in Model 1 the suggestion may impact production early on, but then it converges to the same level. In Model 2 the suggestion increases production by about 10%. These results are also confirmed by a two-sided Wilcoxon rank-sum test where the unit of observation is average production at the session level which can be found in the Online Appendix.

These results are consistent with theoretical predictions. Subjects learn to ignore the suggestion in Model 1, where theory predicts it should not have an impact, while we find that the suggestion increases production when using money is an equilibrium.

4.4 Production in Meetings 1 and 2

In Model 2 there is a choice about how to perform the experiments. One possibility, that we did not pursue, is to use have Players 2 and 3 specify contingent plans before observing offers. The upside of this is that there would be nothing the players could use to infer whether they are in meeting 1 or 2. However, it also makes the experiment seem less like dynamic economic interaction. Hence we ran it as a sequential game. The issue this creates is that sophisticated participants may try to make inferences about which meeting they are in based on how long they wait for an offer. As a matter of fact, in our exit surveys, some subjects assigned the role of Player 2 or 3 said that they tried just that,

As shown in Section 2, there are still monetary equilibria when waiting time is a noisy signal, as long as it is noisy enough. Should production in meeting 1 exceed meeting 2, this is evidence of sophisticated reasoning, which we find rather intriguing. Consider the following regression,

$$P = \beta_0 + \beta_1 \times M_2 + \beta_2 \times m \times M_2 + \beta \times m \times M_1 + C,$$

where the new variable m identifies whether the production is taking place in meeting 1 or 2. In the regressions we tried various controls, and considered the interaction of meeting and suggestions, but the effects are small, insignificant and not robust to the specification; results are quantitatively and qualitatively the same with or without these variables. Meetings without a money offer are dropped, leaving 1,708 meetings, where 1,047 are meeting 1 and 661 are meeting 2.

Finding 3 *Comparing production in meetings across models: production in Model 2 is 20% lower in meeting 2; Production is 30% higher in Model 2 for meetings 1 and 2.*

Table 6: The impact of Meeting on Production

	M_2	$m \times M_1$	$m \times M_2$	$S \times M_1$	$S \times M_2$	# of Obs.
All Rounds	0.2606**	−0.2459***	−0.2099***	0.0779	0.1857**	1,708
	(0.0919)	(0.0378)	(0.0326)	(0.1465)	(0.0703)	
Rounds 1–3	0.0637	−0.3383***	−0.1654	0.4039***	0.1654	365
	(0.2206)	(0.0348)	(0.1423)	(0.0942)	(0.2223)	
Rounds 4–15	0.3085***	−0.2240***	−0.2215***	−0.0027	0.1889**	1,343
	(0.1063)	(0.0523)	(0.0140)	(0.1746)	(0.0688)	

Note: Standard errors in parentheses are clustered at the session level.

Support for finding 3 is in Table 6 and Figure 4. Table 6 shows that, as before, behavior in early rounds is very different from later rounds. In Model 1, subjects tend to produce 0.25 less in meeting 2. In Model 2, there is no significant difference between production in meetings 1 and 2. That is consistent with subjects not knowing in which meeting they are in. However, in games 4–15 subjects produce about 0.22 less in both models, and both coefficients are significant at the 1% level. Of course, because the information is not perfect, production is still 0.30 higher in Model 2 compared to Model 1, in meeting 2, because production falls by about the same amount in both models.

Thus, it appears that subjects may be able to infer to some degree which meeting they are in, but the inference is noisy, as otherwise we would not observe higher production in Model 2. As detailed in Section 2 such behavior is consistent with equilibrium play when the time of meeting is random.

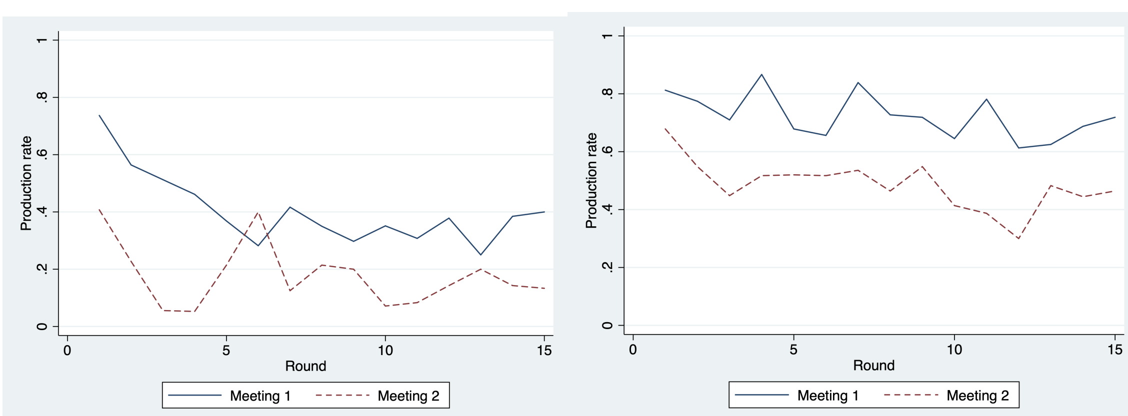

Figure 4: Production by Model and Meeting

Figure 4 depicts average production by round for meetings 1 and 2. The panel on the left shows production in both meetings for Model 1, while the one on the right shows it for Model 2. The interpretation, again, lines up fairly well with theory. Production is lower in meeting 2 for both Models 1 and 2. For Model 1 this should not be the case, but it is still not a surprise as Player 2 can always hope that Player 3 accepts the money, while there is no such possibility for Player 3. Production in meeting 2 is still substantially higher in Model 2, which rationalizes production in meeting 1. To see this, note that the payoff from consuming in the game is 3, while the cost of production is 1. From Figure 5, production occurs in about 50% of the meetings. Then we have that $0.5 \times 3 = 1.5 > 1$, so producing in meeting 1 is optimal given behavior in the experiment.

4.5 Discussion

Our results are largely consistent with theoretical predictions, but there are some departures. The main departures include production by Player 3 in Model 1 and production by Players 2 and 3 in Model 2 without money.[10] Given that production in Model 1 is significantly different from zero, one may wonder whether other-regarding preferences could play a role. To test this, we re-ran the regressions including subjects' scores from social value orientation, SVO, as a control,

$$P = \beta_0 + \beta_1 \times SVO + \beta_2 \times M_2 \ + \beta_3 \times S \times M_2 \ + \beta_4 \times S \times M_1 + C.$$

The SVO measure is constructed using outcomes from generalized dictator games which differ in how costly it is for a player making the offer to give utility to the receiver. Details are provided in the Online Appendix (see also Murphy et al. 2011, who first suggested this measure). However, for our purposes, all that matters is that low values are interpreted as caring less much about others, while

[10] Production in Model 1 by Player 2 tends to be higher than by Player 3, which can be in part rationalized by the observation that occasionally Player 3 chose to produce for the token.

high values indicate some kind of social preferences, such as altruism or inequality aversion.

Table 7: The Impact of Social Value Orientation

	M_2	$SVO \times M_1$	$SVO \times M_2$	$S \times M_1$	$S \times M_2$	# of Obs.
All Rounds	0.2070***	−0.0057**	0.0008	0.0997*	0.0923**	1,708
	(0.0619)	(0.0025)	(0.0012)	(0.0530)	(0.0364)	
Rounds 1–3	0.3180***	−0.0016	−0.0017	0.2251**	0.0456	365
	(0.1083)	(0.0026)	(0.0022)	(0.0869)	(0.0690)	
Rounds 4–15	0.1795**	−0.0069**	−0.0015	−0.0617	0.1035***	1,343
	(0.0707)	(0.0028)	(0.0015)	(0.0609)	(0.0340)	

Note: Standard errors in parentheses are clustered at the session level.

Table 7 reports on the results\. While we conjectured that high production in Model 1 would be correlated with prosocial preferences, there is no evidence at all for this. On the contrary, we find that the *SVO* variable has a negative impact on production in Model 1 and no significant effect in Model 2. Moreover, in our main specification, and alternatives considered for robustness, the magnitude of the impact is very small. Deviations from theory seemingly must be explained by other factors.

Hence we move to the exit survey, where subjects reflect and explain their decisions by answering multiple choice and open-ended questions. In the following, we describe the answers by subjects who produced for at least 5 rounds.

In Model 1 without suggestions, only 1 out of 24 subjects who were Player 3 produced in more than 5 rounds, and the answers provided by this subject suggest confusion as much as anything else. In Model 1 with suggestions, 4 out of 16 subjects who were Player 3 produced in more than 5 rounds. One subject appeared to be confused, selecting the option “To increase the chance of trading it for the good with player 3" as the reason to produce for the token. The other three selected the options “to help the other player" and “to follow the suggestion;" or “to help the other player" and “I made a mistake;" or “to help the other player" and “I wanted the token for the sake of it," respectively.

In Model 2 without money, 5 out of 12 Players 2 or 3 produced for more than 5 rounds. Two of these subjects appear confused as they selected "To increase the chance of others producing for me in this game," which is not possible. One player selected "To increase the chance of others producing for me in a following game," suggesting that even though subjects were randomly matched, there may still be some repeated game effects. The remaining two subjects indicated that they produced to "help the other player," with one of them adding that "I made a mistake."

Overall, helping the other player and confusion appear to be the dominant explanations for production choices that departed from theoretical predictions. It is puzzling to find that "help the other player" appears as one of the main reasons to produce when the social value orientation does not seem to explain anything. Perhaps if exit surveys are more often used in experiments, in the future, we may gain additional insight. For now we simply report that certain subjects' play is hard to understand.

However, it is important to emphasize the following: The fact that there are some agents in an economy that use strategies we do not fully understand is not especially relevant for the purposes of this project. As long as there are other agents that are sophisticated enough to understand the environment and play best responses, it is clear from the experimental results that money is essential – we achieve better outcomes with it than without it. It is also clear that suggestions help, which is not a huge surprise, but is still interesting. For society, learning to adopt the institution of monetary exchange in real time is a complicated enterprise, and it is useful to know that having a mediator can help to select better equilibria.

5 Conclusion

This project has further developed simple models where monetary equilibria exist in finite environments, making them better suited to experiment methods. We took these models to the lab for address several issues. Perhaps the main question is, is money essential? The answer is yes in the precise sense that we achieve better outcomes with it than without it, which might not be surprising to the man on the street, but is inconsistent with many economic models: in standard general equilibrium theory money cannot help; in general equilibrium theory with a cash-in-advance constraint, money makes thing worse.

Our experiments are meant to be similar in spirit to work that strives for better microfoundations in monetary economics, and in particular, they feature bilateral trade, random matching, and information frictions. It is nice, we think that models in theory and the lab mesh well, and that is where using finite models is key. Other innovations here include the notion of making suggestions, not in an effort get the results we want, but simply as a coordination device, and it is comforting to find that suggestions were more likely to have an impact on subjects when they were not inconsistent with best responses. We also used exit surveys and other information to try to understand what subjects were thinking or what they cared about when they played something that is not a best response. As is not too surprising, some subjects did things that are hard to explain except perhaps by confusion. Having said that, what may be more surprising is that others were remarkably sophisticated in their reasoning, making about their role in the game from the timing of events.

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