Is Money Essential? An Experimental Approach*

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Abstract

Money is called *essential* when better outcomes are incentive feasible with money than without it. We study essentiality theoretically and experimentally, using finite-horizon monetary models that suit our purposes well in the lab. Following mechanism design, we also study the effects of strategy recommendations when they are incentive compatible and when they are not. Results show the use of money and welfare are significantly higher in treatments where it is essential, and recommendations help when incentive compatible but not much otherwise. Sometimes money gets used when it should not, and we investigate why using surveys plus measures of social preferences.

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1 Introduction

A central issue in economics is to understand what makes money a socially useful institution. Based on Hahn (1973, 1987), money is said to be *essential* if more desirable outcomes are incentive feasible with money than without it. This is particularly relevant for fiat currency, an object that may have value even though it is intrinsically useless (Wallace 1980). While it has no such role in traditional general equilibrium theory, there are by now various formalizations, surveyed in Lagos et al. (2017) and Nosal and Rocheteau (2017), where frictions make fiat money essential. In this literature, it is commonly understood that three ingredients are needed for essentiality: a double coincidence problem; limited commitment; and imperfect information.

A double coincidence problem means there are gains from trade that cannot be fully exploited by pure barter. In the spirit of Jevons (1875), suppose you are in a world where agents specialize in production and consumption, meet bilaterally at random, and engage in quid pro quo exchange. It may be rare (a coincidence) to meet someone who produces what you like, and very rare (a double coincidence) to meet someone who produces what you like plus likes what you produce. A venerable notion is that money is useful because it permits trade in single coincidence meetings. Yet this is not sufficient for essentiality, as ex ante payoffs are typically higher if agents simply produce when asked. So if they can commit to produce when asked, they would agree to do so, and efficient outcomes can be sustained without money.

If they cannot commit agents may be tempted to renege when asked to produce, rendering the commitment solution inconsistent with dynamic incentives. Yet that is still not enough for essentiality if trading histories are observable, since desirable outcomes can often be supported without money, akin to cooperative equilibria in the repeated-game literature: agents who do not produce when asked are punished by having others not produce for them in the future. This can be described as a credit arrangement, with punishments interpreted as denying future credit to those who fail to honor obligations, as in Kehoe and Levine (1993). As Kocherlakota (1998) emphasizes, such punishments must be precluded for money to be essential.

Conventional wisdom is this: if it is incentive feasible to implement monetary exchange and trading histories are publicly observed, a credit arrangement like the one described above is also incentive feasible, and it is at least as good if not better in terms of welfare. This suggests that essentiality requires information frictions, and while there are different ways to capture such frictions (e.g., see Gu et al. 2016), the common thread is that it must be hard to monitor, communicate or keep records of what happens in pairwise meetings – in Kocherlakota's (1998) terminology, there must be imperfect memory – hindering punishments for bad behavior.

In this context, Wallace (2001, 2010) refers to the view that essentiality is salient as the *mechanism design approach* to monetary economics, and argues that mechanism design methods are attractive because they provide a clear distinction between the environment and the rules of the game mapping actions into outcomes, so given a set of feasible mechanisms, it is possible to decide whether money is essential.[1] What may not have been anticipated is that this leads to models of monetary exchange that are in some ways ideally suited to experimental economics, because the theory is tractable enough that its properties are well understood, and transparent enough that subjects in the lab should be able to comprehend the details, yet the outcomes are not obvious because there are multiple equilibria due to the self-referential nature of liquidity (what you accept in payment depends on what others accept).

There has by now emerged a significant body of experimental monetary economics.[2] However, previous papers do not address our main issue, which is to ask,

[1] As Wallace (2010) puts it, "The mechanism-design approach to monetary theory is the search for fruitful settings or environments in which something that resembles monetary trade actually accomplishes something – or, in Hahn's (1973) terminology, settings in which money is essential." For those interested in history of thought, Hahn actually talked about the essentiality of a "sequence economy" where the sequence of trades may not lead to Arrow-Debreu outcomes. If the sequence is inessential, money might be a way of registering transactions, but nothing important is lost by focusing on Arrow-Debreu. To properly study monetary economics, therefore, we must analyze economies where the trading sequence is essential – as is certainly the case in what follows.

[2] Brown (1996), Duffy and Ochs (1999, 2002) and Duffy (2001) experiment with Kiyotaki and Wright (1989); Jiang and Zhang (2018) use Matsuyama et al. (1993); Rietz (2019) uses Curtis and Waller (2000); Camera and Casari (2014) use something like Kiyotaki and Wright (1993); Duffy and Puzzello (2014*a*,*b*) and Ding and Puzzello (2020) use Lagos and Wright (2005) or its extension by Zhang (2014). Marimon and Sunder (1993) and Marimon et al. (1993) run experiments on OLG models, which appear different, but can actually be nested into the framework presented below.

from a mechanism design perspective, if money helps achieve better welfare outcomes in theory and in the lab, and in both cases for the same reasons. To this end, we work with finite-horizon models, which have advantages in the lab where the game must end at some finite time T. In particular, two environments are considered, identical in all aspects except that agents may or may not know where they are in the sequence of trading opportunities: in one, monetary exchange is an equilibrium outcome, even with a finite horizon, and is superior to the best outcome without money; in the other, there is no monetary equilibrium. Hence a small change in specification takes us from a case where money is theoretically essential to one where it is not.

Intuitively, in the case where monetary exchange is an equilibrium outcome, subjects in the lab can be interpreted as giving up something of value for money because they rationally put positive probability on being able to exchange it later for something they value more. In contrast, in environments where trade ends with probability 1 at $T < \infty$, without uncertainty over where agents are in the trading sequence, accepting fiat money cannot be an equilibrium by standard logic: assuming they understand the game, no one should sacrifice anything at T to get money; so no one at $T-1$ should sacrifice anything to get it; and by backward induction fiat currency should never be valued. Therefore, in standard models with $T < \infty$, if subjects accept money in trade in the lab, one cannot be sure why, but it cannot be because they rationally expect to spend it later.

Experimentalists address this in various ways. Often random termination times are used, where the game ends with some probability after each round. This is meant to generate discounting, as assumed in infinite-horizon models, but does nothing to avoid the backward induction argument if there is still a hard stop at $T < \infty$.[3] Another idea for implementing infinite-horizon monetary theory in finite experiments is to assign value to cash held at T based on what payoffs would be if the game were

[3] Going beyond monetary economics, consider Selten et al. (1997): "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" (see also Cooper and Kuhn 2014, Fréchette and Yuksel 2017 or Jiang et al. 2021.) To be clear, our claim is *not* that taking standard monetary models to the lab is without value – we have done and continue to do that – but here we provide an alternative.

to continue (Marimon and Sunder 1993; Jiang et al. 2021). This is interesting, but treads close to giving up on the fiat nature of fiat currency, as does any experiment with subjects getting a real payoff from finishing up with cash. In our framework, in equilibrium, genuine fiat objects can be used as media of exchange despite $T < \infty$, and agents accept them because they rationally expect to spend them later.

This follows up on previous work in which some of us were involved, Davis et al. (2020), which draws on Kovenock and de Vries (2002), and is related to the analysis of bubbles in Allen et al. (1993) or Allen and Gorton (1993), and ultimately to Samuelson's (1987) discussion of how a lack of common knowledge about T ameliorates end-game effects. What is novel is that we use these insights to study essentiality in the lab (while Davis et al. 2020 also experiment with finite-horizon monetary theory, they do not take a mechanism design approach, or consider strategy recommendations, or try to explain anomalous outcomes the way we do, as discussed below). One especially novel exercise here is a clear controlled experiment comparing two environments with money, where in one there is a monetary equilibrium and in the other there is not, which, perhaps surprisingly, has not been done before.

As mentioned, we go beyond previous papers by considering strategy suggestions or recommendations – e.g., "always produce in exchange for money" – as a device to deal with the coordination problem endemic to fiat currency. The idea, related to Myerson (1986), is that mediation may help with coordination, although, importantly, it is always possible for agents to ignore the mediator. We think recommendations are consistent with mechanism design, and with a standard interpretation of equilibria going back to Nash (1950): give agents a strategy profile and see if they deviate. While it is quite rare in experimental economics to consider suggestions, we feel they are appropriate for the issues at hand, and in any case we want to know if they serve mainly as a coordination device, or subjects simply follow them blindly.[4]

[4] The reluctance to use suggestions in experimental economics is typified by Croson (2002): "the researcher must be careful to... avoid suggesting the desired results to the subjects either explicitly or implicitly." A few papers do consider suggestions (e.g., Duffy and Feltovich 2010; Huyck et al. 1992), but mostly about which equilibrium to play; we do that, plus consider suggestions that are inconsistent with equilibrium, which should not be followed in theory but that does not mean they will not be followed in the lab. No previous work on monetary economics has done that.

To preview the model, suppose there are three agents and two rounds of trade. Also suppose agents being offered money do not know if they are in the first or second round. Accepting money in the second round is rational for an agent that puts high enough probability on it being the first round. Thus monetary exchange can be consistent with equilibrium even when all players know the horizon is finite, and it yields higher ex ante payoffs than can be achieved without money. Yet questions arise. Do agents necessarily use money when a monetary equilibrium exists? No, according to theory, as there always coexists a nonmonetary equilibrium. Might agents accept money when there is no monetary equilibrium? No, according to theory, but in experiments they sometimes do, and we want to understand why – is it due to mistakes, social preferences (agents caring about others) or something else? This is addressed using exit surveys and measures of social preferences extracted from auxiliary experiments that we correlate with subjects' behavior.

To summarize: (i) We compare environments with and without money. (ii) In environments with money we compare specifications where monetary exchange is an equilibrium and where it is not. (iii) We compare cases with and without recommendations, both when following them is incentive compatible and when it is not. (iv) We use theory that allows valued fiat currency with a finite horizon. (v) We focus squarely on essentiality.[5] (vi) We use surveys and measures of social preferences to gain insight into anomalous behavior. (vii) We make some experimental design choices different from related studies, including our earlier work, to minimize repeated-game effects – subjects believing their current actions impact future actions of others – that may have plagued past results.[6]

[5] Essentiality is discussed by Camera and Casari (2014) and Duffy and Puzzello (2014*a,b*), but there money is not essential: the credit system described on pp. 1-2 is implementable. They ask if subjects still use money, which is interesting, but does not bear on essentiality. Suppose, e.g., there is an efficient credit equilibrium, but we are mired in an inferior no-credit equilibrium. Then adding money may be helpful, but it is not essential if the efficient credit outcome is incentive feasible.

[6] There are two standard ways to run experiments with dynamic games: the "strategy method" where ex ante subjects make conditional decisions for each possible information set; and the "direct-response method" where they observe previous play before deciding. We adopt the latter, as it better captures the dynamic nature of the theory, and use it consistently in all treatments, which is not the case in Davis et al. (2020). In combination with agents having fixed roles and being randomly matched, the new design should reduce repeated-game effects (more on this below).

In terms of results, the experiments are largely consistent with theory. Payoffs are significantly higher when money is introduced if a monetary equilibrium exists. If a monetary equilibrium does not exist, introducing money initially increases economic activity, but the impact soon dissipates as subjects seem to learn that accepting it lowers their payoffs. Recommendations help if following them is incentive compatible, but subjects soon learn to ignore them otherwise. When theory says subjects should not accept money, sometimes they do, and, to our surprise, measures of social preferences do not correlate with this. Based on exit surveys, social preferences do play a role, although some subjects say they simply made mistakes. At the same time, other subjects are quite sophisticated, in that they try to infer their position in the trading sequence based on the time it takes to meet a counterparty, which led us to a generalization of the baseline model incorporating such inferences.

2 Theory

There are two environments, Model M and Model N, that are identical except for the information structure, and the labels M and N indicate that the former model has a monetary equilibrium while the latter does not. A common feature is that there are 3 agents and 2 sequential, pairwise meetings; and in each meeting one agent is a producer while the other is a consumer of an indivisible good. This can be considered a truncation of a standard random-matching model or an OLG model. When those models include fiat currency they assume the horizon is $T = \infty$. We can do that, too, but need not, as fiat currency can be valued with infinite or finite T.[7]

Nature determines the roles of players randomly. First there is meeting 1, where one agent is a consumer and called Player 1, while the other is a producer and called Player 2 (everything goes through with pure exchange where there is an opportunity cost of giving up an endowment instead of a production cost). Player 1 may or may

[7] What follows easily extends to any $T < \infty$, with or without random terminations at $t < T$, but we stick to $T = 2$ for two reasons. One is that it should minimize the chance that subjects irrationally regard big T as "approximately" ∞. The other is that, as a referee noted, small T is part of what makes the game easy to learn in the lab.

not be endowed with money, an indivisible, intrinsically useless token. Then there is meeting 2, where Player 2 is a consumer and Player 3 is a producer.

In the first meeting, possible actions for the consumer are: walk away without trading; ask for the good for free; and, if endowed with money, offer it in exchange for the good or offer it for free. If an offer is made, the producer can accept or reject. In the second meeting, possible actions are the same, although whether the consumer has money now depends on what happened in the first meeting. Then the game is over. In each meeting, if a producer gives the good to a consumer the latter gets utility u while the former gets $-c$, a production (or opportunity) cost. Given $u > c > 0$, before nature determines types it is ex ante Pareto efficient for agents to produce in all meetings.

Where the two models differ is that in Model M some agents do not know if they are in meeting 1 or 2, while in Model N the timing of meetings is common knowledge. In particular, in Model N, Player 3 knows the meeting is the second meeting, and so there only exists an autarkic nonmonetary equilibrium. To confirm this, notice it is irrational for Player 3 to bear cost c in the second meeting unless Player 2 gives something of value in exchange, and all that can potentially be offered is money, which is worthless since the game ends after that meeting. So in second meeting money is not valued, and therefore in the first meeting it is not valued, and hence the unique equilibrium enatails no trade, the same as the unique equilibrium without money.

In Model M, when matched with a consumer the producer does not know if it is the first or second meeting. Without money the unique equilibrium is autarky, and with money that is still an equilibrium, but there is also a monetary equilibrium with trade in both meetings as long as $u > 2c$. To confirm this, suppose a producer believes others will produce when offered money. Then the probability of getting to spend the money after receiving it is $1/2$, the same as the probability of the meeting being the first rather than the second. Hence the expected payoff to producing for money is $\frac{1}{2}(-c+u)+\frac{1}{2}(-c) > 0$. Thus, monetary exchange is an equilibrium, and money is essential because without it the unique equilibrium is autarky with expected payoff

0 for all agents. Now, the realized payoff to Player 3 is $-c$ upon getting stuck with money, but this is still desirable because ex ante payoffs are higher, or, amounting to the same thing, average payoffs are higher if the game is played multiple times. Money thus expands the strategy set in both Models M and N, but in Model M it also expands the set of equilibrium outcomes.

There is also a symmetric mixed-strategy equilibrium, where all producers accept money with probability $2c/u$, or equivalently, at least in a version with a large number of players, an asymmetric pure-strategy equilibrium, where a fraction $2c/3$ of the population always, and the rest never, accept money. In related models this kind of partial acceptability is sometimes said to be nonrobust, although there are ways of dealing with that (e.g., Shevchenko and Wright 2004). In any case, a feature of the mixed equilibrium is that monetary exchange is mechanically more likely in the first than second meeting, since the latter requires the former.[8]

Model M turns into Model N if all actions become publicly observable, which can be considered perfect memory. There is no equilibrium other than autarky with perfect memory. Hence, we provide a counterexample to the generally accepted proposition that money is at best an imperfect substitute for memory, a proposition that seems to follow from Kocherlakota (1998), as discussed in a general way by Wallace (2001, 2010). It is based on the idea that anything one can do with money one can also do with memory, and often one can do strictly better with memory. Here money strictly dominates memory. Indeed, it is incomplete knowledge of the timing that allows fiat currency to be valued, and that is what allows an improvement on autarky, the unique equilibrium with perfect memory.[9]

While this baseline model serves our purposes nicely in the lab, there is an ex-

[8] There are also sunspot equilibria, where money is accepted in some states but not others. While experimenting with sunspots in our framework may be interesting, it must be relegated to future work (see Marimon et al. 1993 for experiments on sunspots in OLG models, something we would eventually like to consider in our framework).

[9] Awaya and Fukai (2017) is a previous counterexample to the idea that memory always beats money, but it is much more complicated, so ours constitutes a bit of a contribution. One might say it arises from money containing *some but not all* information about the past, related to work on optimal opacity (Andolfatto et al. 2014; Dang et al. 2017): in our context, if an outside party knows whether agents are in meeting 1 or 2, agents are better off ex ante if that party keeps quiet.

tension that is interesting for its own sake, and especially relevant in light of the experimental results discussed below. Although in theory Model M has players unable to distinguish between the first and second meetings, if the game proceeds in real time, inferences may be possible based on how long it takes to meet a potential trading partner. Since this sometimes happens in our experiments, we now show monetary equilibria still exist if waiting time is a *noisy* signal.

There are different ways to formalize this, but suppose for simplicity that agents can 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 notation). Assume meeting 1 can occur at t_E or t_M and meeting 2 at t_M or t_L, generating a signal-extraction problem: agents cannot tell meeting 1 from 2 when $t = t_M$. The probability distribution over $\{t_E, t_M, t_L\}$ conditional on being in meeting 1 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. Similarly, the distribution conditional on being in meeting 2 is

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

If a meeting occurs early (late) the producer knows it is the first (second). The inference when being offered money at $t = t_M$ is more subtle, and the interpretation of getting a money offer depends on producers' acceptance strategy, because if players do not accept money then a money offer reveals it is meeting 1. If there is an equilibrium in which money is accepted for sure at $t \in \{t_E, t_M\}$, Bayes rule implies that the producer has posterior beliefs

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

when offered money at $t = t_M$. If it is meeting 2 the agent that just produced cannot trade money for goods, but in case it is meeting 1 there is a chance that the money can be used to get the good.

However, if the next producer can detect that it is meeting 2 there will be no exchange. Hence, conditional on signal t_M and being in the first meeting trade occurs in the second meeting if the next producer also receives signal t_M, which happens with probability r. The expected payoff from accepting at $t = t_M$ is thus

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

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 $qru/(q+r) \geq c$.

The point is that monetary equilibria still exist if the signal provided by waiting time is not too precise. Notice $q = r = 1$ is Model M and $q = r = 0$ is Model N, so the extension spans these environments. Also, notice production rates will be higher in meeting 1 than meeting 2 in this extension, as in the mixed strategy equilibrium mentioned above, but now that is true even conditional on the consumer having money in meeting 2.

3 Experimental Design

We now describe our general approach, relegating details to online Appendices.[10] Treatments include cases with and without money, cases with money in Models M and N, and cases with and without suggestions. Table 1 summarizes this, where treatments are labeled with M or N for Model M or Model N, with 1 or 0 indicating if there is money, and with another 1 or 0 indicating if there are suggestions. Previous work focuses on comparing treatments with and without money. We do that, plus we compare Model M and N with money to investigate the importance of strategic considerations – in both cases, strategies contingent on monetary offers are feasible, but in theory accepting is only consistent with equilibrium in Model M.

As regards suggestions, with money the recommendation is to offer money and produce in exchange for it; without money the recommendation is to always produce.

[10]Go to www.sultanum.com/papers/Money_Essential_Instruction_and_additional_results.pdf for all of the Appendices. Appendix G has the full instructions given to subjects; the others mainly contain alternative statistical analyses, designed to check robustness.

TABLE 1: Treatment and Session Characteristics

Treatment	Money	Suggestions	# of Sessions	# of Subjects per Treatment (Session)
M-0-0	No	No	4	45 (9,9,12,15)
M-1-0	Yes	No	4	51 (12,12,15,12)
M-1-1	Yes	Yes	4	48 (9,12,15,12)
M-0-1	No	Yes	4	51 (12,15,12,12)
N-1-0	Yes	No	6	72 (12,12,12,15,9,12)
N-1-1	Yes	Yes	4	48 (12,12,12,12)

NOTE.—M or N stand for Model M or Model N; the first digit is 1 or 0 for money or no money; and the second digit is 1 or 0 for suggestions or no suggestions.

Notice: (i) in Model N, following the suggestion is not incentive compatible or Pareto superior; (ii) in Model M with money it is incentive compatible and Pareto superior; (iii) in Model M without money it is Pareto superior but not incentive compatible. This helps us disentangle if: (i) suggestions coordinate behavior; (ii) subjects do what we suggest even if it is not in their narrow self interest; (iii) they act based on other considerations, perhaps a desire to achieve better social payoffs.

To provide experience, it is standard for subjects to play multiple rounds. Unfortunately, this may make them regard the experiment as a repeated game. Some puzzling results in Davis et al. (2020) (e.g., money has big effects when it should not) seem attributable to this. To allow learning while minimizing repeated-game effects we randomly group players in each round. While some subjects interact more than once, they are anonymous, and the number of participants is large enough that reputation building is difficult. Also, in Model N a subject is Player $i \in \{1, 2, 3\}$ in every round, and in Model M a subject is either Player 1 or randomly assigned 2 and 3 in every round. This further diminishes incentives to try to achieve cooperative outcomes. One can imagine, e.g., that Player 3 could produce hoping that it would make others more likely to do so later in the experiment, but such considerations are less of an issue given the way we assign subjects to roles.

Each experiment has multiple parts. First instructions are read aloud, followed by a quiz to see if subjects understand. Then there are 15 rounds of play in either Model M or N. Next subjects complete an exit survey and demographic survey. Appendix G provides details, but, in brief, the demographic survey asks about gender, age, English proficiency, and field of study, and was included because several past experiments find such characteristics can matter.[11] Finally, subjects play a series of generalized dictator games designed to elicit information about social preferences, the idea being that in the theory agents only care about their own payoffs, but they might care about others in the lab, and this is a way to measure that.

At the beginning of a treatment with Model N, each participant is randomly assigned a role as Player $i \in \{1, 2, 3\}$, which they keep for all 15 rounds. In each round, groups of three are formed by randomly drawing one of each type. Player 1 is endowed with a token. To simplify the choice set in the lab, we change the model in Section 2 slightly by assuming a consumer can either offer money for the good or not; then the producer either produces or not.[12] After this happens twice, in the first and the second meeting, the round is complete, and players are randomly reassigned to new groups, except in round 15 when the session ends.

Model M treatments are similar, except that Player 1 subjects stay in that role for all 15 rounds while the others are either Player 2 or 3 with equal probability in each round, and are uninformed about their role when they decide to produce. In monetary treatments with Model M, Player 1 is endowed with a token and can offer it in exchange in meeting 1, but, different from Model N, the recipient accepts or rejects not knowing if it is meeting 1 or 2. Then, if there is another meeting and Player 2 has a token, it can be offered to Player 3. Player 3 accepts or rejects while similarly uninformed. Then payoffs are tallied and subjects are randomly assigned to new groups, except in round 15 when the session ends.

[11] Croson and Buchan (1989) find women return significantly more wealth than men in trust games, and Eckel and Grossman (1998) find that women donate twice as much to anonymous partners in dictator games. Marwell and Ames (1981) find economics students contribute less than others in public good games, Carter and Irons (1991) find they accept less and keep more in ultimatum games, and Frank et al. (1993) find they defect more in the prisoner's dilemma. Based on those findings, we decided to look into this in our experiments, although it turned out that no interesting differences across demographic characteristics actually emerged.

[12] The consumer gets the good for free if no offer of money is made but the producer still produces, which sometimes, but not often, happens in the lab. What we eliminate from Section 2 are the (dominated) strategies for the consumer: walk away without trading; and offer money for free. Obviously this does not matter in theory and simplifies subjects' choice set in the experiments.

The monetary treatments with recommendations are the same, except we included the following message:

> **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.*

In Model M without money, Player 1 makes no decision, and others decide whether to produce despite not being offered a token, and the message is:

> **A suggestion**: *If you are not Player 1, you may consider choosing to produce. This is simply a suggestion. Feel free to follow it or not.*

In all treatments subjects start with 3 points, then earn $u = 3$ points from consumption and lose $c = 1$ points from production, keeping payoffs nonnegative. Three out of the 15 games are randomly selected for actual dollar payments (while evidence is mixed, Charness et al. 2020 find that paying for only a subset of games is at least as effective as paying for all of them). Each point is worth 2 dollars, while tokens are worth 0, as explicitly described in the instructions: "The token does not yield points directly and cannot be transferred from one game to another."

In the second part of a session subjects play a sequence of generalized dictator games, and from the results we compute a SVO (social value orientation) score as in Murphy et al. (2011). Details are in online Appendix A, but the basic rationale is to see whether social preferences help explain departures from predictions of the theory. Every subject plays 15 generalized dictator games and payoffs are determined from one randomly selected round where the subject is a proposer and one where the subject is a receiver.

We ran four sessions for each treatment, except for Model N without recommendations, where we ran six.[13] This took place between 2020 and 2022 at the IELAB

[13] The reason is the following: We started in the lab, then had to move online due to the COVID pandemic. After two online sessions for the treatment where we had lab data, we found the results were very similar, so we did the rest online. See Appendix B for more detail.

at Indiana University or online. The subject pool consisted of Indiana University students recruited via the Online Recruitment System for Economic Experiments (Greiner 2015). The IELAB experiments were programmed using zTree (Fischbacher 2007), while the online experiments were programmed using oTree (Chen et al. 2016). Every subject participated in only one session. The number of subjects per session ranged from 9 to 15, depending on how many showed up from the recruitment procedure. In total there were 315 subjects, and they earned on average $18.65 for 45 to 60 minutes of their time.

Although there are several auxiliary results discussed below, the experiments were designed mainly to address the following three questions:

> **Question 1.** *Is there more production with money than without it in Model M?*
>
> **Question 2**. *Is there more production in Model M with money than in Model N with money?*
>
> **Question 3**. *Do suggestions have more of an impact in Model M with money than in Model M without money or in Model N with money?*

4 Main Results

The first objective of the experiments is to see whether money is a useful instrument for the reasons emphasized in theory. Fig. 1 provides and overview. In particular, recall **Question 1**: *Is there more production with money than without it in Model M?* The answer is yes. In Fig. 1 the left panel shows the frequency of production in Model M in the treatments where, theoretically, money can be valued, while the right panel shows it for the other treatments, two without money, and two with money but without a monetary equilibrium. Production is aggregated over both meetings, and the darker lines are averages across treatments. Two features stand out: production is higher in the left than in the right panel; and in the left panel it is relatively stable while in the right it declines fairly sharply over the rounds, presumably because subjects figure out that production reduces payoffs. The message is similar in Fig. 2, which focuses on comparing Model M with and without money, showing production with (without) suggestions on the right (left), and including production conditional on the buyer having money.

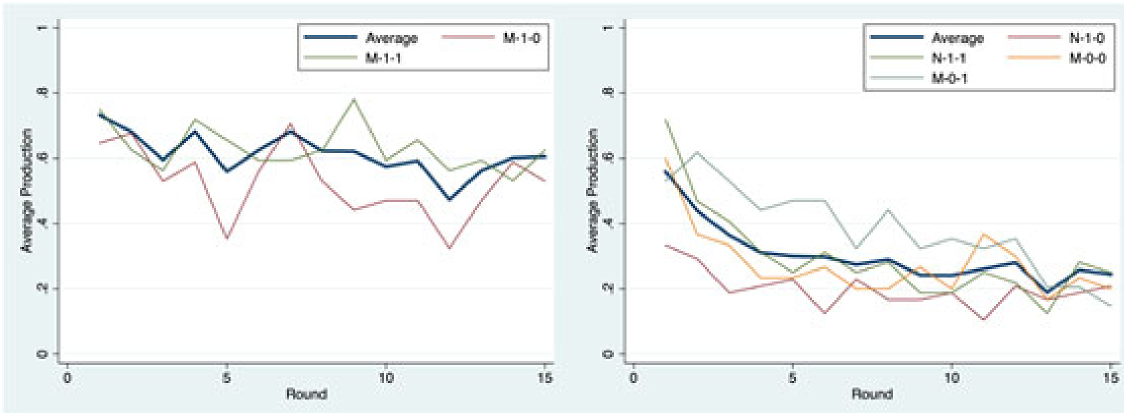

Fig 1. Average production by treatment. The left (right) panel shows the treatments with (without) a monetary equilibrium.

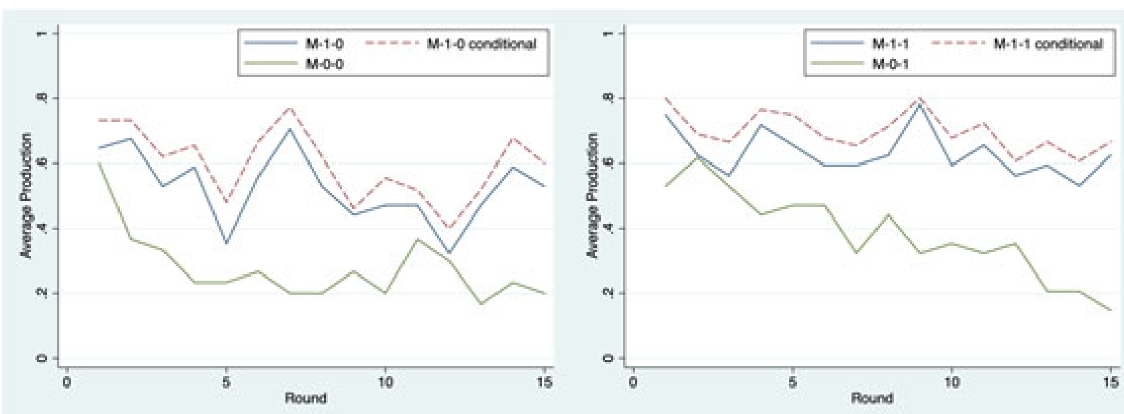

Fig 2. Average production in Model M. The left (right) panel shows treatments without (with) suggestions. Shown are average production unconditional and conditional on a buyer having money.

Table 2 provides statistics. Production averaged over meetings holds relatively steady in Model M with money, averaging 52% without suggestions and 62% with suggestions. In contrast, without money production decreases to 25% in the last five rounds as subjects gain experience, and suggestions do not appear to matter much. Table 2 reports p-values from WMW (Wilcoxon-Mann-Whitney) tests where the unit of observation is average production at the session level. For each case we perform tests for different segments of the data: all rounds, rounds 1-5, rounds 6-15, and rounds 11-15. This allows us to study effects of experience, and shows production is significantly higher with money than without it especially in later rounds.[14]

TABLE 2: Production in Model M

	Average				WMW p-values	
	M-1-0	M-0-0	M-1-1	M-0-1	M-1-0 v M-0-0	M-1-1 v M-0-1
All Rounds	0.52	0.28	0.62	0.39	0.029	0.114
Rounds 1-5	0.55	0.37	0.64	0.52	0.114	0.343
Rounds 6-15	0.51	0.24	0.61	0.32	0.029	0.057
Rounds 11-15	0.48	0.25	0.59	0.25	0.057	0.057

NOTE.—The p-values from the WMW test are exact and two-sided. There are 4 observations per treatment.

Note that the frequencies of production in the preceding paragraph, 52% without suggestions and 62% with suggestions, are not conditional on the consumer having money, and obviously if money is not accepted it in the first meeting it cannot be offered in the second. Fig. 2 also shows production conditional on the consumer having money, which is around 60% without suggestions and 69% with them, while Table 3 provides statistics. Again, production is higher with money than without it, similar to earlier findings by Camera and Casari (2014) and Duffy and Puzzello (2014), although in those papers money is not essential (recall fn. 5). The results differ significantly from Davis et al. (2020), where money is essential in theory, but their evidence does not support that – money improves allocations most in treatments where it should not even be accepted – which we think is due to design choices, as mentioned above.

In Model M with money, it is offered and accepted for production in the majority, but not all, of the meetings. There are alternative ways to interpret some people not accepting it when others seem to be coordinating on monetary equilibrium. Some deviations from theory are naturally expected in any experiment, but, in any case, money is essential if some, not necessarily all, agents rationally produce in exchange for it. Also, in principle, partial acceptability could be due to agents coordinating on the symmetric mixed-strategy equilibrium, where everyone accepts money with

[14] Appendix C describes production by session, while Appendix D complements the non-parametric analysis in the text with parametric analysis. Table D.1 in Appendix D reports results from linear probability and probit models, with controls for meetings and rounds. Consistent with the results in the text, the results in Appendix D show production in Model M is significantly higher with money than without it.

TABLE 3: Production in Model M Conditional on Money in Meeting

	Average		WMW p-values	
	M-1-0	M-1-1	M-1-0 v M-0-0	M-1-1 v M-0-1
All Rounds	0.60	0.69	0.029	0.029
Rounds 1-5	0.64	0.72	0.057	0.114
Rounds 6-15	0.58	0.68	0.029	0.029
Rounds 11-15	0.55	0.65	0.029	0.029

NOTE.—The p-values from the WMW test are exact and two-sided. There are 4 observations per treatment.

probability $2c/u$, or on an asymmetric pure-strategy equilibrium where $2c/u$ of the agents always, and the rest never, accept money. In the experiments $2c/u = 2/3$, which works well because the number of subjects is always divisible by 3. While one might think it is unlikely that agents could coordinate on such equilibria, 2/3 is remarkably close to what is observed in the experiments.

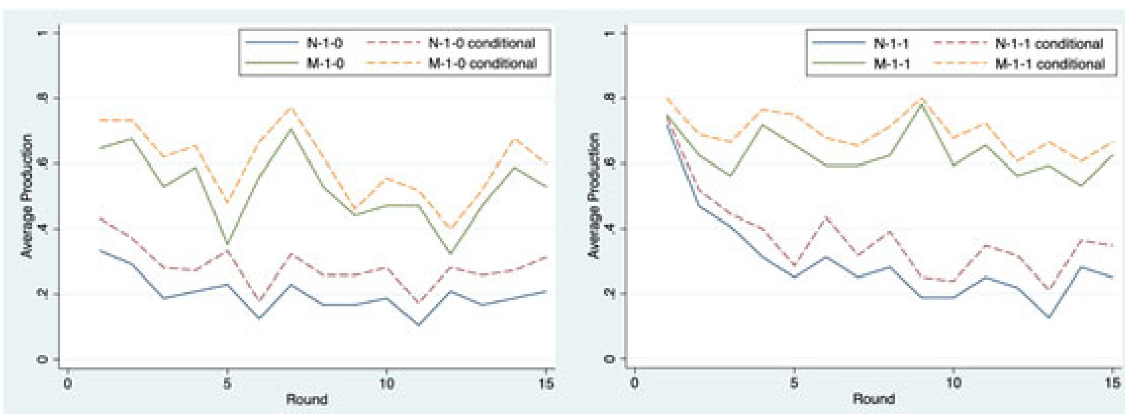

Fig 3. Average production in Models M and N. The left (right) panel shows monetary treatments without (with) suggestions. Shown are average production unconditional and conditional on a buyer having money.

Now recall **Question 2:** *Is there more production in Model M with money than in Model N with money?* Yes. As Fig. 3 and Table 4 show, in Model N without suggestions production averages 20% over all rounds, falling from 25% in the first five rounds to 18% in the last five. With suggestions, it averages 30% over all rounds, falling from 43% in the first five rounds to 22% in the last five. Of course, theory says it should be 0, but again we do not expect all everyone to be a rational, self-interested agent. In Model M with money and no suggestions, production is 52% over all rounds, only declining from 55% to 48%. With suggestions it is 62% across all rounds, declining from 64% to 59%. Table 4 reports p-values for production at the session level.[15]

The conclusion is that production in Model M with money is significantly higher than in Model N with money, and it is worth emphasizing that this comparison is novel. Previous studies contrast the same environment with and without money, not different environments with money where monetary exchange is incentive compatible in one but not the other, which we think provides an important complementary evaluation of essentiality. In some previous work, subjects tend to use money regardless of whether that is consistent with equilibrium. Our findings indicate that subjects do not use money automatically – it matters whether a monetary equilibrium exists – which was not obvious ex ante.

TABLE 4: Production in Treatments with Money

	Average				WMW p-values	
	N-1-0	M-1-0	N-1-1	M-1-1	N-1-0 v M-1-0	N-1-1 v M-1-1
All Rounds	0.20	0.52	0.30	0.62	0.009	0.029
Rounds 1-5	0.25	0.55	0.43	0.64	0.019	0.086
Rounds 6-15	0.18	0.51	0.23	0.61	0.009	0.029
Rounds 11-15	0.18	0.48	0.22	0.59	0.009	0.029

NOTE.—The p-values from the WMW test are exact and two-sided, and there are 6 observations in treatment N-1-0 and 4 in the other treatments.

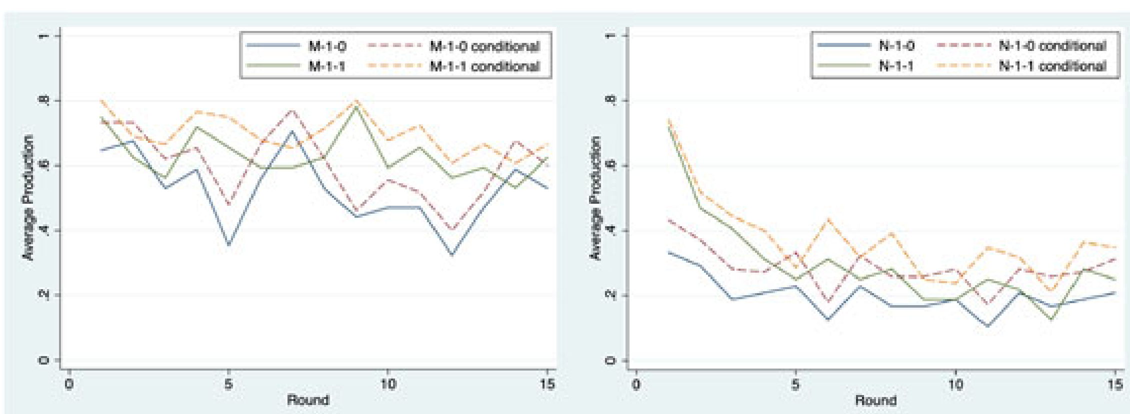

Fig 4. Average production in monetary treatments. The left (right) panel shows Models M-1-0 and M-1-1 (N-1-0 and N-1-1). Shown are average production unconditional and conditional on a buyer having money.

[15] Again the Appendices complement the non-parametric analysis in the text with parametric analysis. Table D.2 reports results from linear probability and probit models, with controls for meeting and round. Similar to the results in the text, with money production in Model M is significantly higher than in Model N.

Now recall **Question 3:** *Do suggestions have more of an impact in Model M with money than in Model M without money or in Model N?* Yes. In theory, when a monetary equilibrium does not exist, recommending that subjects produce for money should not matter, and when it exists the same suggestion may help them coordinate on exchange with fiat currency. The left panel of Fig. 4 and Table 5 summarize production in early, middle, and late rounds, plus p-values. The message is this: as subjects gain experience, outcomes can be improved by suggestions when they are consistent with equilibrium, but not otherwise, even if following the suggestions would generate a Pareto superior outcome.[16]

We conclude from this that the impact of suggestions in Model M is attributable to coordination, as opposed to a desire by subjects to please the experimenter or to achieve higher social payoffs (consistent with findings by Duffy and Feltovich 2010, although their experiments were not on monetary economics). In the treatments where the unique equilibrium is nonmonetary, suggestions can raise production in early rounds, but as Table 5 shows, the initial boost is significant only for Model N, where the p-value is 0.076. In later rounds, production appears to converge toward the same level, and all p-values are above 0.45. In contrast, in Model M the suggestion increases production by about 10% on average in later rounds, or over all rounds, and the effects are statistically significant.

5 Additional Findings

We now explore how subjects' behavior correlates with social preferences as captured by SVO scores, demographic characteristics, and major field of study, to see how factors not captured by standard theory matter. We also discuss responses from exit surveys designed to shed further light on subjects' motivation. Finally, we ask how production varies across meetings 1 and 2.

To begin, we regressed production on agents' SVO scores, demographic characteristics and major field of study separately for each model. As for demographic

[16] Once again the Appendices complement the analysis in the text with results from linear probability and probit models, with controls for meeting and round. Similar to results in the text, those results indicate suggestions have a stronger impact in Model M with money than in Model M without money or in Model N. To summarize, the material in the Appendices shows all the main findings are robust to different ways of examinig the data.

TABLE 5: Effect of Suggestions

Average						
	N-1-0	N-1-1	M-1-0	M-1-1	M-0-0	M-0-1
All Rounds	0.20	0.30	0.52	0.62	0.28	0.39
Rounds 1-5	0.25	0.43	0.55	0.64	0.37	0.52
Rounds 6-15	0.18	0.23	0.51	0.61	0.24	0.32
Rounds 11-15	0.18	0.22	0.48	0.59	0.25	0.25

WMW p-value			
	N-1-0 v N-1-1	M-1-0 v M-1-1	M-0-0 v M-0-1
All Rounds	0.114	0.086	0.400
Rounds 1-5	0.076	0.400	0.114
Rounds 6-15	0.457	0.057	0.571
Rounds 11-15	0.609	0.057	1.000

NOTE.—The p-values from the WMW test are exact and two-sided, and there are 6 observations in treatment N-1-0 and 4 in the other treatments.

characteristics and field of study, they are included because past work shows they sometimes matter (recall fn. 11). However, they do not have significant effects in our experimental data. As for SVO scores, we expected that they would be positively correlated with individuals producing whether or not that is consistent with equilibrium. However, the general finding is that coefficients on SVO tend to be insignificant or have the wrong sign, suggesting that either social preferences do not explain why agents produce when theory says they should not, or that SVO scores are not a good measure of social preferences in our experiments.[17]

To further investigate this we employed exit surveys, which turned out to provide more insight than SVO regressions. In surveys from the treatments with money, we asked Players 2 and 3 why they produced in exchange for the token, and Tables 6 and 7 give the number choosing each answer; for the nonmonetary treatments, we asked why they produced, and Table 8 gives those numbers. Note the columns need not add to the number of subjects because they can choose more than one answer.

Starting in Model N with money, but without a monetary equilibrium, without suggestions, among the 24 subjects that acted as Player 3, 17 never produced, con-

[17] Appendix E regresses production on individual characteristics separately for Model M and N with money, as well as model M without money. The coefficient on SVO is significant at the 5% level only in rounds 6-15 in Model N and then it is negative; it is positive but insignificant in Model M with money; and it is positive and significant only in early rounds in Model M without money. Demographic characteristics and field of study are not significant.

Table 6: Reasons for Monetary Exchange in Model N

		Player 3		Player 2	
		N-1-0	N-1-1	N-1-0	N-1-1
a	Not applicable: I was never in this situation	17	6	3	0
b	To increase the chance of trading it for the good with another player	1	1	18	14
c	I made a mistake	2	2	1	1
d	To help the other player	2	5	8	7
e	I wanted the token for the sake of it	4	4	2	0
f	To follow the suggestions	-	4	-	7
g	Other reason. Please explain:	0	1	3	1

NOTE.—This table shows the number of responses to the question: "If you were offered the token and you produced in exchange for the token, why did you do it? Check all that apply." Option (f) applies only to N-1-1. The total number of subjects is 24 for treatment N-1-0, and 16 for treatment N-1-1.

sistent with theory. The rest produced for money. Among those, 2 said they wanted to help the other player, which to us sounds like social preferences. Then 4 said they wanted the token for its own sake, 2 said it was a mistake, and 1 said it was to increase the chance of trading with another player, which to us all sound like confusion. In the treatment with suggestions, more subjects produced for money, and of those that did 4 said they were following the suggestion. For subjects that acted as Player 2, many indicated they produced for money to increase the chance of trading it to another player, which can be rationalized if sometimes Player 3 accepts money even if that is not equilibrium play (see below).

Moving to Model M with money, the survey does not distinguish between Player 2 and 3 since roles are uncertain when actions are taken. From Table 7, strategic considerations play a dominant role: most subjects produced for money and said they did so to increase the chance of trading in the next meeting, consistent with monetary equilibrium. Finally, for Model M without money, Table 8 shows some subjects produce when in theory they should not, and many said they did so to increase the chance of others producing for them in this game and more to increase the chance of others producing for them in the next game.

Another result seen in Fig. 6 is that production in Model M with money is higher in the first than the second meeting. The difference is statistically significant and

Table 7: Reasons for Monetary Exchange in Model M

		M-1-0	M-1-1
a	Not applicable: I was never in this situation.	1	1
b	To increase the chance of trading it for the good with player 3 in case I turn out to be player 2	31	29
c	I made a mistake	0	1
d	To help the other player	7	8
e	I wanted the token for the sake of it.	1	2
f	To follow the suggestion.	-	5
g	Other reason. Please explain:	1	6

NOTE.—This table shows the number of responses to the question: "If you were offered the token and you produced in exchange for the token, why did you do it? Check all that apply." Option (f) applies only to M-1-1. The total number of subjects is 34 for treatment M-1-0, and 32 for treatment M-1-1.

TABLE 8: Reasons for Production in Model M without Money

		M-0-0	M-0-1
a	Not applicable: I never produced	6	5
b	To increase the chance of others producing for me in this game	15	15
c	To increase the chance of others producing for me in a following game	16	24
d	I made a mistake	1	1
e	To help the other player	10	18
f	To follow the suggestion	-	4
g	Other reason. Please explain:	1	3

NOTE.—This table shows the number of responses to the question: If you produced in a game, why did you do it? Check all that apply." Option (f) applies only to M-0-1. The total number of subjects is 30 for treatment M-0-0, and 34 for treatment M-0-1.

big, around 15% (see Appendix F for details). This is production conditional on the consumer having money, so the explanation is not simply that subjects are playing a mixed-strategy equilibrium, as discussed in Section 2. Instead the finding suggests that subjects can to some extent distinguish between the two meetings, as in the extension of the baseline with noisy signals. Sophisticated subjects may make inferences based on how long they wait for a meeting, and not produce if they infer a high probability of meeting 2.

At the end of the sessions, Players 2 or 3 were asked whether they could tell what their positions were, and some of them said that they tried to guess based on the time they had to wait to have access to the decision screen. However, some also said their guesses were often wrong, suggesting that the inference is noisy, consistent with the extension in Section 2. In the lab, during the experiment, subjects proceed to meeting 2 after everyone in their group finishes meeting 1, so a longer waiting time can also be due to slow group members, making inference noisy in practice. The fact that the difference between production in meeting 1 and 2 is bigger in Model M than Model N also lines up nicely with theory.

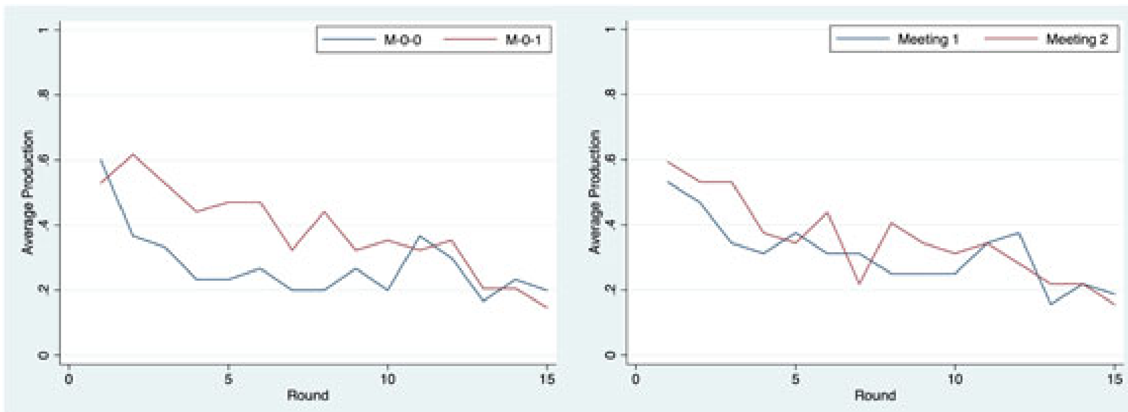

Fig 5. The left (right) panel shows average production in Models M-0-0 and M-0-1 (production by meeting using pooled data from Models M-0-0 and M-0-1).

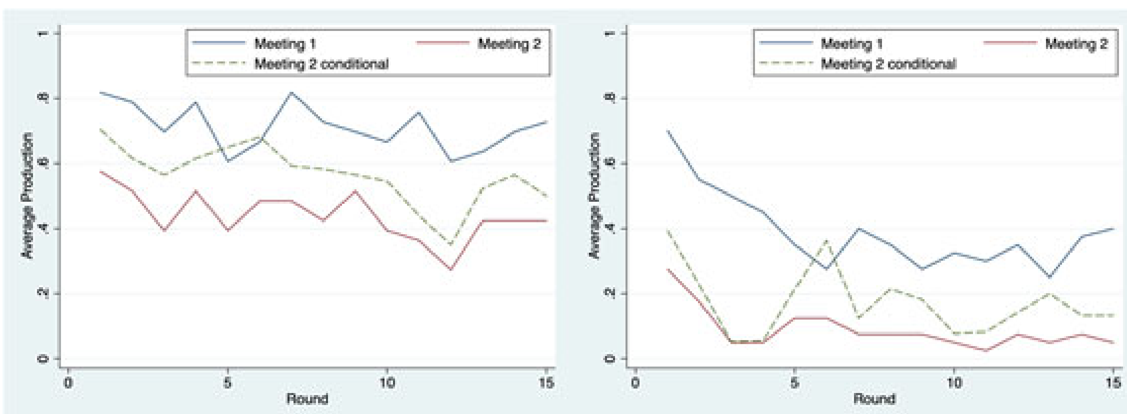

Fig 6. Average production by meeting. The left (right) panel pools data from treatments M-1-0 and M-1-1 (N-1-0 and N-1-1). Shown are average production unconditional and conditional on a buyer having money.

As a final result, recall that in Model N subjects know which meeting they are in. Hence, in theory no one should produce for money in either meeting, but in practice the two meetings are not quite the same, and this shows up in Fig. 6, where the right panel displays production in the first and second meeting for treatments based on Model N. This can be explained by noticing that if you accept money in the first meeting there is at least a chance you can spend it in the next meeting – not in equilibrium, but in the experiment – while if you accept it in the second meeting there is no such chance. Hence, even if someone is rational and selfish, there is a rationale for accepting money if it is believed that other players may accept it due to irrationality or social preferences. Of course, it may also be due to limited ability to use backward induction. In any case, in Model M without money there is no systematic difference between the two meetings, again consistent with the benchmark model, as can be seen in the right panel of Fig. 5.[18]

6 Conclusion

This paper studied, theoretically and experimentally, models of monetary exchange that can have valued fiat currency even with a deterministic termination time. In terms of methods, we focused on essentiality and took a mechanism design approach that sometimes included strategy recommendations. In terms of findings, first, the introduction of money had large and statistically significant effects on production in Model M, consistent with theory, and with past experiments. Second, the effect of money was substantially smaller and declined quickly with experience in Model N, again consistent with theory, and not something checked in past work. Together these results provide evidence that money is used for the strategic reasons pinpointed by the theory.

While money should not be accepted in Model N, sometimes it was accepted, which did not surprise us too much. Based mainly on exit surveys, if not the correlation with social value orientation, this may be due social preferences, although some subjects admitted to simply making mistakes. Another finding is that suggestions improved outcomes when they were incentive compatible, but not much otherwise, implying their impact does not come from subjects feeling obliged to follow them. Yet another finding is that some subjects used waiting time as a noisy indicator of position in the trading sequence, which led us to extend the benchmark model to incorporate inferences. This extension has the property that monetary exchange is

[18] Appendix F reports regression results verifying that production is significantly lower in the second meeting in Model M and in model N. It also shows that production does not decline across meeting in Model M without money.

more likely in the first than the second meeting, consistent with the experimental evidence.

In terms of extensions, one idea is to add more agents or meetings to see how that affects backward induction. Another is to study alternative ways to coordinate play – e.g., in addition to suggestions, one could consider different specifications for private or public histories, or perhaps pre-play communication (cheap talk). Additionally, there are other ways to get monetary equilibria in finite environments – e.g., one can add a coordination or hawk-dove game in the final period, with equilibrium selection depending on whether money was accepted in the past. Also, there are many interesting applications of monetary theory in experimental economics, mentioned in fn. 2, studying commodity as well as fiat money, two-country or two-money models, versions with divisible goods or divisible money, and OLG environments, and it may be fruitful to revisit those applications using finite-horizon models. This is left to future work. For now, we conclude that the experimental results line up fairly well with theory, and that the exercise taught us a lot about monetary economics, especially about essentiality and the mechanism design approach.

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