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PLAYING WITH MONEY*

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Abstract

Experimental studies in monetary economics usually study infinite horizon models. Yet, the time constraints of the laboratory sessions in which these models are conducted create finite horizons that imply monetary equilibria cannot exist. Moreover, laboratory subjects do not treat the probabilistic termination rule typically used in a manner consistent with the discount factor that the rule is intended to replace. Thus, it is unclear whether these experiments evaluate subjects' use of money to ameliorate trading frictions as an equilibrium phenomenon, their inability to understand backward induction, or features of games that promote the use of money behaviorally, even when doing so is not an equilibrium strategy. To address this issue, we present a pair of finite-horizon games where monetary exchange is an equilibrium, and report an experiment that evaluates behavior in these games in light of a finitely repeated alternative where monetary exchange is not an equilibrium.

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Playing for absurdly large stakes, gamblers can express their disdain for money as a medium of exchange. Jackson Lears (1995), “Playing with Money,” *The Wilson Quarterly*, 19(4), 7-23.

1 Introduction

There has been much progress over the last twenty-five or thirty years in monetary economics, and by now several internally consistent models exist where intertemporal exchange is facilitated by the use of assets as media of exchange.¹ It is clear from common sense and the historical literature why one might want to use a medium of exchange: it facilitates trade because it can be easier to trade x for y and then y for z , rather than trade x for z directly. The traditional explanation for why the former is easier is that the latter, a pure barter transaction, requires a double coincidence of wants, whereas the former, a monetary transaction, requires two single coincidences of wants.²

This paper studies money theoretically and experimentally, although we focus on somewhat nonstandard ways in which monetary exchange can emerge as an equilibrium or an essential (welfare-enhancing) outcome. As is well known, in frictionless general equilibrium theory, money cannot be valued or essential, so one has to make some rather ad hoc assumptions to study the issues at hand – e.g., that counter to the standard usage adopted above, fiat currency gives agents direct utility, or that agents are only allowed to trade x for cash and cash for y when they prefer to trade x for y directly. Such reduced-form assumptions are presumably short cuts to modeling explicitly what money is and what money does, but this arguably renders them ill equipped to address interesting and important policy issues in monetary theory and policy analysis.

More microfounded models (see the surveys mentioned in footnote 2) take a different approach. First, they have agents trading with each other, unlike a standard Walrasian model, where they only trade along their budget lines; note that this includes cash-in-advance models where they trade along truncated versions of their

¹To be clear, by an asset we mean a store of value, in the sense that if one acquires it at date t and holds it to date $t' > t$, it can be used, with positive probability, to acquire something else or otherwise achieve some desired goal. By a medium of exchange, or money, we follow the classic definition (e.g., Wicksell 1911) and mean an object that is accepted not for its own account, i.e., not to be used for consumption or production by the receiver but to be traded again for something else. All media of exchange are assets, obviously, but not all assets are media of exchange.

²The literature distinguishes between two kinds of money. Some monies, like coins made of precious metal, may also be directly consumed or used in production, and these are called *commodity money*; others, like inconvertible government or private bank notes that are to a first approximation useless in consumption and production input, are called fiat monies. See the recent surveys by Lagos et al. (2017) and Rocheateu and Nosal (2017) for more on the terminology and history of thought in monetary economics; see Wallace (1980), and some of the other contributions to the same volume, for earlier discussions of the ideas.

budget lines. Second, the trading process plays out in real time in the presence of specialization that can give rise to problems associated with double and single coincidences, as well as explicit frictions including spatial or temporal separation, limited commitment, and imperfect information. These ingredients serve to generate gains from trade, but also hinder barter and simple credit arrangements. Third, there can emerge endogenously in these models a role for an institution like money, where it ameliorates trading frictions.

Monetary theory as just described is almost ideally suited to methods commonly used in experimental economics. Perhaps the best example is the fact that agents in these models trade with each other – which is what usually happens in the lab, even if meetings between agents are implemented via computer terminals, not face to face. Moreover, one can then ask if the relevant institutions, including monetary exchange, emerge as outcomes in the context of the laboratory; and if so, or if not, one can try to understand why. Additionally, it is straightforward to consider different treatments that correspond well to salient features of the theory, in the sense that the parameters of importance can be changed easily, where for different parameters the theoretical outcomes can be quite different.

There is a substantial and growing literature investigating the performance of such microfounded monetary models in the lab. Early examples include Brown (1996), Duffy and Ochs (1999,2002), and Duffy (2001), where the experimental design follows closely the original model of commodity money in Kiyotaki and Wright (1989). Others, such as Rietz (2017), concerns the use of secondary monies (e.g., cryptocurrencies) using the model of fiat money in Kiyotaki and Wright (1993). Yet others, such as Duffy and Puzzello (2014*a,b*), study versions of the more flexible model of fiat money in Lagos and Wright (2005). Camera and Cessari (2014) study a more abstract gift-giving economy related to Aliprantis et al. (2007*a,b*). Jiang and Zhang (2017) and Ding and Puzzello (2017) build on the international monetary model in Matsuyama et al. (1993).³

All these papers study models that in theory are based on an infinite horizon, even though in actual experiments the horizon is, of course, finite. This is problematic because monetary equilibria cannot exist in versions of similar theoretical environments with finite horizons. It remains problematic even in experiment designs that use a random stopping rule to end a game, and even when, as in the papers referenced above, the experimental designs feature repeated supergames or iterations of the probabilistically terminated games, because within each supergame there is a deadline beyond which the session simply cannot continue.

Moreover, considerable evidence suggests that laboratory subjects do not approach a game terminated with a probabilistic stopping rule in a manner consistent

³Also related are Marimon et al. (1993), Marimon and Sunder (1993,1995), and Bernasconi and Kirchkamp (2000), among others, who run experiments on overlapping generations models of the type once championed by Wallace (1980). See also Anbarci et al. (2015) and Berentsen (2017) for still other approaches.

with the discount factor that the probabilistic rule is intended to substitute.⁴ For example, in their meta-analysis of indefinitely repeated prisoners' dilemma games, Dal Bo and Fréchet (2017) observe that while cooperation rates tend to be higher in games where cooperation can be supported as an equilibrium, the fact that cooperation can be supported as an equilibrium doesn't imply that subjects will cooperate.⁵ Rather, in the latter case, cooperation rates are quite varied. As these authors further observe, the game features most critical to determining whether or not players maintain cooperation lie not in dynamic features of the game, such as subgame perfection, but in parameters of the stage game, such as strategic uncertainty and risk dominance.⁶

For these reasons, it is unclear what experiments evaluating monetary models are testing – e.g., the hypothesis that subjects have the ability to use money as a medium of exchange in order to ameliorate trading frictions as an equilibrium strategy, the hypothesis that players are unable to understand backward induction,⁷ or the hypothesis that money emerges due to participants' attention to the static features of a stage game. Indeed, while the papers purport to investigate whether or not subjects find a monetary equilibrium, in fact, at least as a technical matter, monetary equilibria do not exist in the specified environments.

Duffy and Puzzello (2014a), for example, study a version of Lagos and Wright (2005) with a finite number of agents. When this number is relatively small, it is possible to use contagion strategies to support nonmonetary equilibria featuring gift giving that Pareto dominate monetary equilibria, provided agents are sufficiently patient. Their experimental results show, however, that money tends to be used when it is available and that better outcomes are achieved with money than with only gift giving. The investigators interpret this result as suggesting that money is an efficiency-enhancing coordination device, as well as a way to sustain intertemporal trade without explicit commitment or enforcement. But it must be emphasized that the only exact equilibrium outcome in their designs is autarky – no trade in any period – and hence, it is not clear that their results show that money enhances the likelihood of achieving better equilibria. Moreover, although the average production rates did not deteriorate across supergames, within supergames production rates (and the use of fiat money) did taper off with the passing of rounds, a behavioral result utterly inconsistent with the way agents are presumed to treat a discount

⁴In their introduction to a paper investigating the behavioral differences of different termination rules, Fréchet and Yuksel (2017) observe that we know little about whether or not people treat situations where the future is less valuable than the present in the same way as interactions that might exogenously terminate (p. 280).

⁵Dal Bo and Fréchet (2017), Result 2.

⁶Dal Bo and Fréchet (2017), Result 4.

⁷Notably, in McCabe's (1998) early experiment evaluating the use of money as a store of value, he observes the continued use of a fiat money as a store of value even after many rounds of a finitely repeated game, in an environment where use of the fiat money is not part of an equilibrium strategy.

factor, in which agents approach every new period as they approached those in the past.

It seems that an infinite horizon is an essential part of monetary theory. After all, if the horizon is finite, there is no incentive to accept fiat money in exchange for anything of real value in the last period. But then, in the penultimate period every agent understands that money is of no value in the final period, so money cannot be accepted in the penultimate period. By induction, it follows that money cannot be accepted in any period for any finite horizon. We explain this argument within a finite horizon overlapping-generations model along the lines of Samuelson (1958), but the exact same logic applies to all workhorse models with microfoundations in the literature.⁸

In fact, it is actually possible to specify simple models where monetary exchange is essential (welfare enhancing) even with a finite horizon. This point was previously made by Kovenock and De Vries (2002), and should not be surprising in light of the literature on repeated games. In that literature, the following is understood: if there is a unique stage game equilibrium, it is critical whether a repeated game has a finite or infinite horizon; but if there are multiple equilibria in the stage game, as shown by Benoit and Krishna (1985), there is a finite horizon folk theorem similar to the standard one for environments with infinite horizons. In this paper, we develop a pair of simple alternative approaches for dealing with endgame effects that make it possible to interpret experimental results in terms of equilibrium outcomes, and then we report the results of an experiment that evaluates subjects' propensities to use money to improve welfare in each model, relative to a finitely repeated alternative game where no monetary equilibrium exists.

The payoff structure in our first finite horizon model with a monetary equilibrium is much like a conventional monetary model, but it circumvents the backward induction argument much like Allen et al. (1993) and Allen and Gorton (1993) construct equilibria with speculative bubbles by introducing asymmetric information about the time horizon. Only the player who holds the money knows whether it is the first or the second period. This implies that the player who is supposed to accept money must take an expectation: with some probability, there is no next period and the money is useless; but with complementary probability, there is a second period where it can be used. If the gains from trade are large enough, it is possible to support an equilibrium where fiat money is valued in this environment.

The second game with a monetary equilibrium draws more directly on the logic from Benoit and Krishna (1985) and also relates to designs that have been implemented in the experimental literature on repeated games.⁹ Again, there are two

⁸In supplementary Appendix A, we discuss a version of Kiyotaki and Wright (1993), where the same result is true in the case of pure fiat money, but where an arbitrarily small dividend can make money useful for transactions purposes with a long finite horizon.

⁹See Anderson and Wengström (2012) and Cooper and Kuhn (2014), where endgame effects are ruled out theoretically by changing the stage game in late periods to one with multiple equilibria.

periods, and the first has a payoff structure corresponding to a standard monetary model. Unlike the previous game, however, all players can distinguish period 1 from period 2, but the latter is different. In period 2, a game with multiple equilibria is played, and for reasons explained below we use a hawk-dove game. Then, equilibria emerge where a money holder can use intrinsically useless money to “buy” coordination on his or her favorable equilibrium. This justifies players accepting money in the first period and thus mitigates the lack of double coincidence of wants. Prior to setting out these games, we discuss a simple overlapping generations model along the lines of the seminal contribution by Samuelson (1958), which was later adopted to monetary economics by Wallace (1980).

2 Game 1: Overlapping Generations

There is an infinite sequence of agents labeled $t = 1, 2, 3, \dots$, time is discrete, and also labeled $t = 1, 2, 3, \dots$. At each time $t \geq 2$, there is a match between agent t and $t - 1$ that occurs where the young agent t can produce a binary good that is consumed by the “old” agent $t - 1$. It costs c utils to produce the good and $t - 1$ gets utility $u > c$ from consuming. Assuming that the future payoff is discounted by $\beta \in (0, 1)$, the Pareto optimal outcome is for the young to always produce for the old provided that $\beta u \geq c$. If $\beta u < c$ and $u > c$, it is surplus maximizing to always produce, but the first agent is made worse off.

2.1 The Nonmonetary Economy

Assuming that each t can observe all past the transactions and that $\beta u \geq c$, there is a gift-giving equilibrium that implements the first best. In this equilibrium, t produces for $t - 1$ if and only if each $i \leq t - 1$ produced for $i - 1$. Since the on the equilibrium path payoff from playing in accordance with the strategy is $\beta u - c$ while a unilateral deviation on the path gives 0 this is a Nash equilibrium, and since, additionally, a one-shot deviation off the equilibrium path gives $-c < 0$, the (grim-trigger) punishment is credible, so the strategy profile is subgame perfect.

However, the case that is relevant for monetary exchange is when past transactions are unobservable, and then the only equilibrium is autarkic with no production in any period. That is, to enforce the desirable outcome, it is necessary that a player who deviates is punished, which is impossible if past transactions can neither be observed or inferred.

2.2 The Monetary Economy

A fiat money can be used to support the desirable outcome. We endow agent 1 with one indivisible object, referred to as token, that is costless to store, but no agent in the economy derives any consumption utility from holding (or eating). We

then consider the following dynamic stage game at every time $t \geq 2$. First, agent $t - 1$ makes an offer that is a commitment to either transfer the money or not as a function of whether agent t produces the good for $t - 1$. Then, t either produces the good or not, and the coin is transferred in case the offer and the production decision stipulates that it should be.¹⁰ As soon as the coin is not transferred, the continuation game is the same as the nonmonetary economy with past transactions being unobservable. So if the old agent enters a period t without money, the continuation utility is 0. Hence, if each old agent proposes that the young agent should produce in exchange for money (and that the money will not be transferred unless the agent produces), the utility for the young agent to accept is $\beta u - c > 0$, so this is a subgame perfect Nash equilibrium.

2.3 Finite Truncations of the Game

Obviously, it is impossible to implement an infinite horizon game in the laboratory, which creates a challenge. That is, say that there is some last period T when T and $T - 1$ meet. Then, agent T has a strict disincentive to trade the consumption good for the coin since there is no agent $T + 1$ to produce for her in the next period. But then, $T - 1$ would not accept the coin from $T - 2$, and by induction it follows that the only equilibrium is the autarky equilibrium with no production. In fact, the argument doesn't even use subgame perfection, but it applies also using Nash equilibrium or iterated elimination of strictly dominated strategies as the solution concept.

A common response to this issue in experimental work is to use a random termination rule. For simplicity, assume that the game continues with probability π after each round. We then must assume that $\pi u > c$ to guarantee that producing in every period is efficient and supportable as a monetary equilibrium in the infinite horizon model. However, while the probability that the game continues after T periods, π^T , is small when T is large (for $\pi = 3/4$ and $T = 30$ it is 0.00017858209), it is strictly positive for any π and $T < \infty$ so the random termination rule must be combined with a hard stopping rule. The simplest way to do this is to deterministically stop play after T rounds. But then, should round T be reached, T would not accept the money from $T - 1$, which implies that $T - 1$ cannot accept the money from $T - 2$ in equilibrium should round $T - 1$ be reached. By induction, the only Nash equilibrium is still the autarkic equilibrium with no production, so random termination doesn't affect the *theoretical* prediction with fully rational agents from the deterministic truncated overlapping-generations model.

In actual experiments, the hard stopping rule is often not articulated as an explicit maximal period. This, however, doesn't affect the argument. Suppose that

¹⁰A simpler model would have t first produce and then $t - 1$ either hand over the money or not. This would also work but would be a more fragile model as $t - 1$ would be indifferent between handing over the money and not.

the time it takes to play a round is random and that the experiment stops for sure when t^* is reached. Then, there must be some $t_1^* < t^*$ such that the players who meet at $t \in [t_1^*, t^*]$ know for sure that there will be no next period. Hence, the “young” agent cannot accept money in equilibrium at $t \in [t_1^*, t^*]$. Continuing the argument by induction, we again reach the conclusion that there can be no production in equilibrium.¹¹

We use the overlapping generations framework along the lines of Samuelson (1958) for its simplicity. However, the modern monetary economics literature typically uses matching models that have evolved from Kiyotaki and Wright (1989, 1993). We discuss such a model in the appendix. Critically, however, these models also require an infinite horizon for monetary equilibria to exist.

To construct experimental designs that support monetary equilibria with pure fiat money a different approach is needed. One needs to change the games in ways where monetary equilibria can exist despite there being a terminal period. The models in the next two sections develop a pair of pertinent alternatives that include this critical feature.

3 Game 2: Uncertain Position

It is understood that uncertainty about the termination of play can be used to sustain cooperative outcomes in repeated games. The usual way to implement this is to have a random termination rule, but as already been noted, this can’t be exactly implemented in the laboratory. In this example, which builds on Kovenock and Vries (2002), we demonstrate that in a random matching setup it is possible to circumvent end game effects in a model with just two periods and three agents.

Extensions to $n \geq 3$ agents and $T \geq 2$ are possible, but to explain the economics in the simplest possible framework we stick to the case with two periods, three agents, and three goods labeled by $i = 1, 2, 3$. That is, the label of the agent corresponds with the good the agent is able to produce. However, agent i consumes only the good that is produced by agent $i + 1$ modulo 3, meaning that 3 consumes the good produced by 1. Goods are consumed and produced in binary quantities, and the consumer derives utility u from consuming, whereas the producer pays cost c with $c < u/2$. Hence, the utilitarian outcome is for the producer to produce in every single coincidence meeting.

Meetings are bilateral, and to make the example as simple as possible, we assume that there are only three sequences of meetings that occur with positive probability.¹² We assume that:

¹¹Moreover, if subjects are uncertain of the terminal period but aware that the lab session must end by a certain time, uncertainty about what would constitute a terminal period creates a loss of control over the effective probability of continuation.

¹²If the cost is low enough relative to the utility of consumption, we can extend the example to allow for urnball matching in each period.

- With probability $\frac{1}{3}$, agents 1 and 2 meet in the first period and agents 2 and 3 meet in the second period. Denote this sequence by $(1, 2), (2, 3)$.
- With probability $\frac{1}{3}$, agents 2 and 3 meet in the first period and agents 1 and 3 meet in the second period. Denote this sequence by $(2, 3), (1, 3)$.
- With probability $\frac{1}{3}$, agents 3 and 1 meet in the first period and agents 1 and 2 meet in the second period. Denote this sequence by $(3, 1), (1, 2)$.

Provided that gains from trade are sufficiently large, we could have used other matching protocols, such as standard urnball matching, with no qualitative changes. The rationale for these particular sequences is that all meetings are single coincidence meetings and that the producer in the first meeting is the consumer in the second meeting for every sequence, which makes calculations of the relevant probabilities extremely simple.

As in game 1, at most one unit of money is circulating in the economy. To simplify the analysis, in the case of a monetary economy, the agent who is the consumer in the first meeting is endowed with a unit of money for sure.

The most critical assumption is that there is asymmetric information about the sequence of meetings. Specifically, the agent who should efficiently consume in the first meeting (the money holder in the monetary economy) knows which sequence is realized.¹³ In contrast, the producer cannot distinguish between the first and the second period, so player 1 cannot distinguish between period 1 (sequence $(3, 1), (1, 2)$) and period 2 (sequence $(2, 3), (1, 3)$) when meeting player 3, and symmetrically for the other two agents.

3.1 The Nonmonetary Economy

Just as in the truncated overlapping-generations model, the only equilibrium in the model without money is the autarkic equilibrium with no production. To see this, assume without loss that agent 1 produces with positive probability when meeting agent 3. The only way this can be consistent with a rational play is if producing for agent 3 would increase the probability of consuming if 1 meets 2 in the next period. But, in a nonmonetary economy, the probability that 2 produces for 1 in the second period must be a constant and equal to the probability that 2 produces for 1 in the first period. By symmetry, the same argument applies for any pairwise meeting, so we conclude that the unique equilibrium is an autarky equilibrium where no goods are produced or consumed. Indeed, the argument is even stronger, as it establishes that autarky is the unique *rationalizable* outcome (Bernheim 1984).

¹³This is to make sure that there is no fundamental difference between the non-monetary and the monetary economy. Unless we have imperfect recall we have to assume that the money holder can distinguish being endowed with it and earning it in an exchange in a previous period.

3.2 The Monetary Economy

In the monetary economy, we have to take a stance on the bargaining protocol in a bilateral meeting. The assumption we make is that the agent holding money makes a take it or leave it offer to the potential producer that specifies whether the money will be transferred and whether the producer will produce. This can be accepted or rejected, and if it is rejected, nothing is produced or transferred.

As in any micro-founded model of fiat money, there is an equilibrium where money is not valued that replicates the equilibrium of the non-monetary economy. Assuming that producers always reject any offer from a consumer with money, the continuation value of money is the same as the continuation value of not holding money. Hence, producing in exchange for a unit of money makes the producer strictly worse off, implying that this is indeed an equilibrium.

However, given that the gains from trade are sufficiently large, there is also a monetary equilibrium in which agents follow the following strategy:

- A consumer with a unit of money proposes to give up the money in exchange for the consumption good.
- A consumer with no money makes any feasible proposal (the most straightforward assumption is to assume that money is observable, in which case a proposal to exchange money for the good is considered not feasible).
- A producer accepts to produce if offered money and doesn't produce if offered no money in exchange.

Clearly, there is no profitable deviation for a consumer with a unit of money, as such a consumer always consumes. Also, given the response of the producers, there is nothing a consumer without a unit of money can do to get a unit of the consumption good, so there is no profitable deviation here either. Finally, a producer in a meeting knows that with probability $1/2$ there is another period, in which case she will be a consumer with a coin, which in equilibrium will be accepted. Hence, a producer has a strict incentive to accept the proposal to produce in exchange for a unit of money if $c < u/2$. We conclude that the monetary economy has an equilibrium that replicates the first-best outcome.

The reader may notice that the conclusion depends on parameters. If $u/2 < c < u$, the construction doesn't work and autarky is the unique equilibrium outcome also with money. This is fully consistent with the existing literature on monetary economics, where the point is that it is *possible* that money can overcome frictions that result from the lack of double coincidence for the right parameter configurations. That is, as stressed by Kocherlakota (1998), money serves as a substitute for record keeping in the equilibrium, but money is less precise than record keeping, so sometimes it cannot achieve full efficiency. This imperfection is intuitively why money is only helpful if the difference between the consumption utility and the production cost is large enough.

4 Game 3: Role Identification

The insight in Benoit and Krishna (1985), that a multiplicity of stage game equilibria can be used to sustain reputational equilibria in finitely repeated games, drives this example. Kovenock and De Vries (2002) discuss a related situation, but we use a stage game in which equilibria are not Pareto ranked to make our construction less fragile.

Consider a game with two periods. In the first period, the underlying environment is like in the previous example. There are three agents and three goods labeled by $i = 1, 2, 3$. That is, the label of the agent corresponds with the good the agent is able to produce. However, agent i consumes only the good that is produced by agent $i + 1$ modulo 3. Goods are consumed and produced in binary quantities, and the consumer derives utility u from consuming, whereas the producer pays cost c with $c < u$. For simplicity, we assume that only one of the three possible single coincidence meetings is drawn at random with equal probabilities in period one. Also, in the monetary economy, we assume that the consumer is endowed with a coin and can make a take it or leave it offer to the producer just like in the previous example.

The strategic situation in the second period differs completely. Here we assume that the player who was not matched in period 1 is matched with the producer in period 1 and that this player cannot observe the outcome of the period 1 meeting.

Here, we assume that two players are drawn at random to play a Hawk-Dove game, which we, for simplicity, parametrize as

	Hawk	Dove	
Hawk	$\frac{v}{2} - e, \frac{v}{2} - e$	$v, 0$,
Dove	$0, v$	$\frac{v}{2}, \frac{v}{2}$	

where we think of the first period producer as the row player and $\frac{v}{2} - e < 0$. This static game has three Nash equilibria, (Hawk,Dove), (Dove, Hawk), and a mixed strategy equilibrium that will not be used in the construction below.

4.1 The Nonmonetary Economy

Since the game played in period 2 has three Nash equilibria, the nonmonetary economy now has multiple equilibria, provided that agents know whether they are row or column players. But, again, there is no way to construct an equilibrium in which agents transact in the first period. In the second period, one of the Nash equilibria will be played, so the payoffs cannot be made contingent on whether or not the first period producer produced. Neither cheap talk nor sunspots will help. Cheap talk fails because in the absence of money there is no way one can make any inference about first period behavior, so there is no way to stop a non-producer from mimicking a producer. Sunspots are useless as the expected payoffs would still not depend on the decision to produce.

4.2 The Monetary Economy

For period 1, we maintain the assumption from section 3 that the agent holding money makes a take-it-or-leave-it offer to the potential producer that specifies a token transfer if and only if the producer produces. The producer may either accept or reject this offer, but if it is rejected, nothing is produced and the potential consumer keeps the token. In the second period, an agent holding money can transfer it to the other agent (or simply show it).¹⁴

As in both previous examples, equilibria exist in the monetary economy that replicate those in the non-monetary economy. If the players in the second period make the same equilibrium selection regardless of whether or not the period 1 producer transfers the money, no incentives to produce exist in the first period. Hence, any non-monetary equilibrium outcome can be replicated as a subgame perfect equilibrium in the monetary economy.

However, there may also be equilibria where money is valued. Suppose that the players follow the following strategies:

- In period 1, the consumer offers the producer the money in exchange for the consumer good.
- In period 1, the producer accepts the offer.
- In period 2, the first period producer transfers the money to the agent who was not active the first period.
- In period 2, (Hawk, Dove) is played if the first period producer transfers the money if possible (meaning that the first period producer is the hawk).
- In period 2, (Dove, Hawk) is played if no money is transferred (meaning that the first period producer is the dove).

Clearly, second period play is consistent with subgame perfection as players play a Nash equilibrium of the hawk-dove game after any history of play, and, since it improves the equilibrium selection, a player holding money has a strict incentive to give it to the other player. Obviously, the first period consumer has a strict incentive to follow the postulated strategy as it results in positive utility from giving up an object with no value (for that player). The only question is whether the producer in the first period is willing to produce, which will be the case as long as $v > c$.

It may also be noted that the monetary equilibrium with production in the first period is renegotiation proof. Because play shifts between equilibria that are not Pareto rankable depending on whether there is a monetary transfer, the two players

¹⁴Given that money is valued in the last period because it is a coordinating device, showing it or handing it over is the same in the last period. We could have had a more elaborate end game with more than one period, and then it would be critical to actually “pay” for the coordination by handing the money over.

in the second period do not have common interests to undo the coordination that supports good behavior in the first period. This is an advantage in comparison with using a coordination game at the end, which would be more fragile, as it would fail the test of renegotiation proofness.

Importantly, the two examples developed above are hardly exhaustive. In Appendix A, for example, we consider a game with a payoff structure where the equilibrium outcome in a simultaneous move game is dominated by the sequential (Stackelberg) game obtained by letting one player observe the action of the others before taking an action. Thus, if the second player could condition on the action of the first, it would be possible to support a mutually desirable outcome. In the Appendix, we show that if there is a third player with money, a desirable equilibrium emerges that replicates the Stackelberg outcome. However, the two examples above, together, with the discussion of the overlapping generations, suffice to illustrate the essentiality of infinite horizons in the standard monetary models and show that finite horizon alternatives to the standard models exist in which monetary equilibria exist.

5 A Behavioral Evaluation of the Monetary Equilibria in Finite and Infinite Horizon Models

The simple micro-founded monetary models in sections 2, 3, and 4 advantageously allow a direct assessment of the propensity of subjects to adopt the use of money in explicitly finite horizon contexts, where doing so is variously inconsistent with an equilibrium, or consistent with a welfare-enhancing monetary equilibria by relying on features that are implementable *exactly* in the laboratory.

5.1 Experiment Design

Our experiment involves four player variants of the finitely repeated overlapping generation (OLG), Uncertain Position (UP), and Role Identification (RI) games developed above. In each case, we set the production cost at $c = \$1$ and the utility of consumption $u = \$3$.¹⁵

We implement each game as a series of rounds. At the start of a round participants are randomly assigned an order in sequence $s = 1, 2, 3$, or 4 to make decisions in matches $t = 1, 2$, and 3. For the purpose of simplicity, we refer to the decision makers in a round as players 1, 2, 3, or 4. In the OLG game, at the start of each round participants are told their sequence position. Then players 2, 3, and 4 decide

¹⁵Our prior perception was that a four-player version of these games would give selection of the monetary equilibrium a better chance of emerging in the UP and RI games. Conditional on not being in position $s = 1$, with four rather than three periods, expected earnings in the monetary equilibrium increase from \$0.50 to \$1.00 in the UP game and increase from \$1.00 to \$1.33 in the RM game.

in matches 1, 2, and 3 whether or not to produce for their respective players 1, 2, and 3. If players 2, 3, and 4 all choose to produce, players 1 to 4 earn, respectively, \$3, \$2, \$2, and -\$1, generating a maximum expected earnings of \$1.50. If no player chooses to produce, all players earn \$0.

In the UP game, rounds proceed similarly except that players 2, 3, and 4 do not know their order in sequence when they make production decisions. We implement this experimentally by having these players make production decisions simultaneously, after which the game is played and payoffs determined. Maximum and minimum earnings in the RM game parallel those in the OLG game.

Finally, in the RI game, participants know their order in sequence at the start of each round (as in the OLG game), and in periods 1 and 2, young players 2 and 3 make production decisions for their respective old counterpart players 1 and 2. In period 3, however, player 3 meets young player 4 to play the Hawk-Dove game with $v = 3$ and $e = 2$, which creates the normal form game structure shown as Table 1.

Table 1: A Parameterized Version of the Hawk-Dove Game

	Hawk	Dove
Hawk	-0.5, -0.5	3, 0
Dove	0, 3	1.5, 1.5

If players 2 and 3 both produce, and then players 3 and 4 coordinate on the Hawk-Dove equilibrium in period 3, expected earnings for players 1 through 4 are \$3, \$2, \$2, and \$0, respectively, generating maximum expected earnings of \$1.75. Unlike the other two games, minimum expected earnings are non-zero. In the event that both players 2 and 3 choose to not produce, players 3 and 4 still play the Hawk-Dove game in period 3. While the players in principle could use the labels 3 and 4 to coordinate on pure strategy equilibria, we view coordination on the symmetric mixed strategy equilibrium as the most natural prediction from theory. This yields expected earnings of \$0.38 to each player, thus the minimum expected earnings over all players in the RI game is \$0.19.¹⁶

In each game, we evaluate treatments, both with and without money. Each monetary treatment differs from its non-monetary counterpart in the single respect that player 1 is given a *token* at the beginning of each round. This token has no value in and of itself, but player 1 can pass it to player 2 in exchange for the production good. Provided players 2 and then 3 obtain the token, they may similarly pass it to the next player in the sequence in meetings 2 and 3, respectively.

Table 2 summarizes theoretical predictions for nonmonetary and monetary equilibria in our parameterization of each game. Note that for each game, the non-

¹⁶Earnings rounded to the nearest cent. In a symmetric mixed strategy equilibrium, each player plays Hawk with probability $\frac{3}{4}$ and Dove with probability $\frac{1}{4}$. Expected earnings are $-0.5\frac{3}{4} + 3\frac{1}{4} = \0.375 .

Table 2: Equilibrium Predictions Summary

Equilibrium	Tokens Passed	Units Produced	Hawk-Dove Outcome {t, t+1}	Expected Overall Earnings	Earnings Players 2, 3 and 4
<i>Overlapping Generations (OLG)</i>					
Nonmonetary	–	0	–	\$0.00	\$0.00
Monetary	0	0	–	\$0.00	\$0.00
<i>Uncertain Position (UP)</i>					
Nonmonetary				\$0.00	\$0.00
Monetary	3	3	–	\$1.50	\$0.75
<i>Role Identification (RI)</i>					
Nonmonetary	–	0	Mix	\$0.19	\$0.25
Monetary	3	2	{Hawk,Dove}	\$1.75	\$1.00

monetary equilibrium is both the *unique equilibrium* prediction in the non-monetary treatment, as well as *an equilibrium* in the monetary treatments.

Starting with the top rows of the table, observe that money doesn't affect equilibrium predictions in the OLG game. In the unique rationalizable outcome, no player accepts a token, and no player ever incurs the cost to produce a unit. As a result, earnings are \$0.00 in the unique equilibrium regardless of whether money is introduced. In contrast, a welfare-improving monetary equilibrium exists in the money treatments of both the UP and RI games. In the monetary treatment of the UP model, the monetary equilibrium increases overall expected earnings over the nonmonetary equilibrium from \$0.00 to \$1.00. Player 1 consumes for sure, doesn't have to produce in this equilibrium, and therefore has the most to gain, but equilibrium earnings for players other than player 1 increase from \$0.00 to \$0.75. In the monetary treatment of the RI game, overall expected earnings are \$1.75 per player, slightly higher than the monetary equilibrium for the UP model. This increase is attributed to the facts that (a) in the monetary equilibrium for the RI game, player 4 does not incur a \$1 production cost, and (b) in the corresponding nonmonetary treatment, expected earnings exceed 0. Notice, however, that expected earnings for players other than player 1 increase by \$0.75 in the monetary equilibrium, just like in the UP model.

5.2 Experimental Procedures

The experiment consisted of nonmonetary and monetary treatments for each of the three games summarized in Table 2, generating a total of six distinct treatments. For each treatment, we conducted a series of three sessions. In each session, a cohort of 16 volunteers were randomly seated at visually isolated computer terminals. Prior to the actual experiment, the participants listened to a recording with instructions while following along on printed copies of their own. Instructions were followed by a quiz of understanding, after which the session began.¹⁷ It appears that the participants understood the instructions well.

Sessions consisted of a sequence of 11 three-match rounds. At the outset of the session, participants are randomly divided into groups of four, which remain fixed for the first 10 rounds. At the beginning of each round, the participants in each group are randomly re-ordered in a sequence of players 1 to 4.

To separate learning from possible reputational effects that may possibly emerge as a consequence of being re-matched with the same participants (albeit in different sequence orders each period), we pause the session after period 10. At this point, participants are given additional instructions for how the final round differs from rounds 1-10:

1. First, participants will be re-matched into new groups. Importantly, under the rematching protocol, each participant will be grouped with three other participants with whom they have not previously interacted and none of whom have previously interacted with each other.¹⁸ The rationale for this is to make participants perceive the last round as a one-shot interaction.
2. Second, both production costs and the return from consumption are tripled, to $c = \$3$ and $u = \$9$ in round 11.

Following round 11, the session ends. Lab dollars are converted to U.S. currency on a 1-to-1 basis; participants are privately paid the sum of their earnings for all periods plus a \$6 appearance fee and dismissed.

A summary of the matrix of treatments appears as Table 3. The experiment was conducted between March 19, 2018, and April 4, 2018, at Virginia Commonwealth University, and involved a total of 288 student volunteers. Participants, mostly upper-level undergraduate business, engineering, and mathematics students, were

¹⁷Sample instructions appear in supplementary Appendix B.

¹⁸Procedurally, the absence of possible contagion that the round 11 re-matching protocol invoked was easy to convincingly explain. In rounds 1-10, subjects were randomly and anonymously assigned a group letter (A-D), as well as a number (1-4). For rounds 1-10, the subjects in each group letter were re-sequenced at the start of each round (thus, for example, a sequencing for members of group C might be C2, C4, C3, and C1. For round 11, groups were re-formed to consist of one member from each group letter A to D, such as A3, B2, C4, and D1.

Table 3: Matrix of Treatments

Game	No Money	Money
Finite Overlapping Generations (OLG)	OLG-NM1, OLG-NM2, OLG-NM3	OLG-M1, OLG-M2, OLG-M3
Uncertain Position (UP)	UP-NM1, UP -NM2, UP-NM3	UP-M1, UP -M2, UP -M3
Role Identification (RI)	RI-NM1, RI-NM2, RI-NM3	RI-M1, RI-M2, RI-M3

recruited with the ORSEE recruitment software. The experiment was written in Z-Tree. Each session lasted roughly 45 minutes. Earnings (including a \$6 appearance fee) ranged from \$2.50 to \$37.00 and averaged \$19.00.

5.3 Results

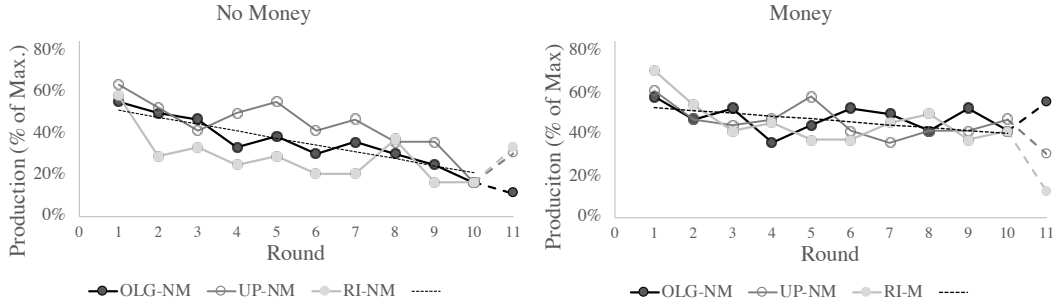
We organize this subsection into two parts. The first part overviews results in terms of the two primary outcomes of interest, (i) how does the addition of money affect production levels and (ii) when money is available, how do players use it? Evaluation of these outcomes allows us to draw a series of four general findings. As will be seen, in some critical respects behavior differs substantially from theoretic predictions.

5.3.1 Overview and General Findings

The sequence of production rates, expressed as a percentage of the maximum possible production levels in each treatment, shown as Figure 1 provides an overview of the effects of money on production levels. For the nonmonetary treatments, shown in the left panel of the figure, production decisions are remarkably similar to the pattern of decaying contributions to a group exchange routinely observed in experiments on voluntary contributions toward public goods.¹⁹ In the initial round, roughly 55% of participants choose to produce. With repetition, production rates slowly diminish to an average of about 17% in round 10. Despite the sharp environmental differences between the public goods contribution game and the games considered here, similar factors may well drive much of the observed decay in each case. Subjects initially approach each situation as a group investment game where they produce out of an expectation of increased earnings through active participation. With repetition, production (contributions) falls as participants increasingly appreciate the strategic aspects of their decisions, a consequence that confirms our design decision to conduct a final round with a re-grouping featuring a no-contagion re-matching protocol, along with increased incentives.

¹⁹See, e.g., ch. 6 in Davis and Holt (1993).

Figure 1: Production rates



In the monetary treatments, shown in the right panel of Figure 1, initial production rates again roughly average about 55%. Unlike their non-monetary counterparts, however, production rates decay considerably more slowly with repetition, falling to about 40% on average in period 10, suggesting that in all games, the addition of money appears to slow and in some treatments to even stabilize production decisions.

Observe also in Figure 1 that round 11 production rates do not simply mimic those observed in the previous round 10 for either the monetary or non-monetary treatments. In the non-monetary treatments, mean production rates for the UP and RI games each roughly double from about 17% to about 33%, while in the OLG treatment they continue their steady downward path from 17% to about 11%. In the monetary treatments, the dispersion of period 11 production rates results are even more varied, with the mean production rate rising from 41% in period 10 to 55% in in the OLG setting, but falling from 47% to 30% in the UP treatment and falling still further, from 42% to 12.5% in the RI treatment. Restart effects are not uncommon in small-group decision-making experiments. Here, however, the varied direction of these effects across treatments suggests that differing dynamics may drive decision-making in each case.

To more formally evaluate production decisions, we regress production decisions against a series of indicator variables $D_j, j \in \{OLG, UP, RI, M\}$ that delineate the three treatments, as well as the presence or absence of money. Specifically, we estimate

$$y_{ijt} = \beta_0 + \beta_{OLG,M} D_{OLG} D_M + \beta_{UP,M} D_{UP} D_M + \beta_{RI,M} D_{RI} D_M + \beta_{UP} D_{UP} + \beta_{RI} D_{RI} + \varepsilon_j + u_{ijt} \quad (1)$$

where y_{ijt} is production decision (0 or 1) of a subject i (1 to 4) in group j (1 to 12) in period t (1 -11). We cluster data by groups and use a robust (White sandwich) estimator to control for possible unspecified autocorrelation or heteroskedasticity. As a rough control for learning, we disaggregate estimates for rounds 1 to 10 into

session halves. Finally, given the different group composition and payoff structure for the final round, we also estimate round 11 results separately.

Table 4: Mean Production Rates

Game	Money	No Money	Money-No Money
<i>Rounds 6-10</i>			
OLG	47.8% ^{†††}	27.8%	20.0% ^{***}
UP	41.7% ^{†††}	35.6%	6.1%
RI	42.5% ^{†††}	22.5%	20.0% ^{**}
<i>Rounds 11</i>			
OLG	55.6% ^{†††}	11.1%	44.4% ^{***}
UP	30.6% ^{†††}	30.6%	0.0%
RI	12.5% ^{†††}	33.3%	-20.8% [*]

Key: [†]Reject the null hypothesis that mean production rates equal 100%. ^{*}Reject the null hypothesis of no difference in mean production rates across the Money and No Money treatments of a game. In each case, one, two, or three markets indicate rejection of the null at $p < 0.10$, 0.05 and 0.01, respectively.

Table 4 summarizes regression results for rounds 6-10, as well as for round 11.²⁰ Looking first at mean production rates for the money treatments of each game, observe that these rates exceed 50% only in round 11 of the OLG treatment with money, and even in this case, at 55.6%, it remains significantly below the 100% level consistent with the efficient outcome. This is a first general finding.

Finding 1. *Given money, groups fail to coalesce on the efficient monetary outcome in every treatment.*

Notice also the differences in production rates across the Money and No Money treatments in each game, shown as the rightmost column of Table 4. For the OLG game, the addition of money sizably and significantly increases production both in rounds 6-10, where the difference is 20 percentage points, and in period 11, where the difference increases to 44.4 percentage points. The same is not true of the UP game, where money increases mean production by an insignificant 6.1 percentage points in rounds 6-10, and fails to increase production rates at all in round 11. Perhaps most

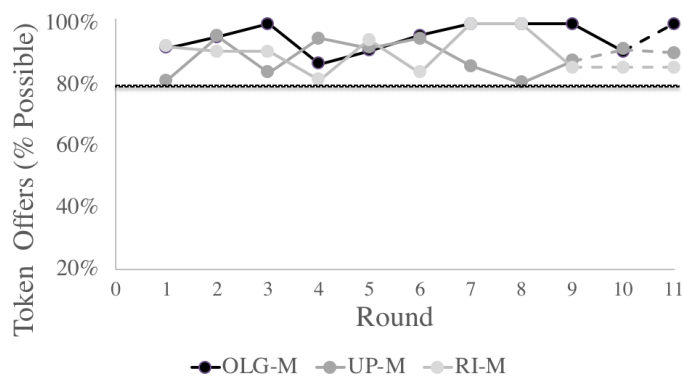
²⁰Summary results for rounds 1-5, as well as primary regression results for all estimates appear as Tables C4.1 and C4.1A in Appendix C. We report linear probability estimates for ease of interpretation. Probit estimates yield substantially identical results. Logit regressions reported as Tables C4.2 and C4.2A in Appendix C generate essentially identical results.

curious are results for the RI game, where in rounds 6-10 money increases production by 20 percentage points on average (significantly different from 0 at $p < 0.05$), but in round 11 production rates fall by 20.8 percentage points (significantly different from 0 at $p < 0.10$). We will consider presently possible reasons for the productivity-reducing effect of money in the final round of the RI game. Nevertheless, we observe here that money consistently improves production rates only in the OLG game. This is a second general finding.

Finding 2. *Mean production rates in the monetary treatment consistently exceed those in the non-monetary counterpart only in the OLG game.*

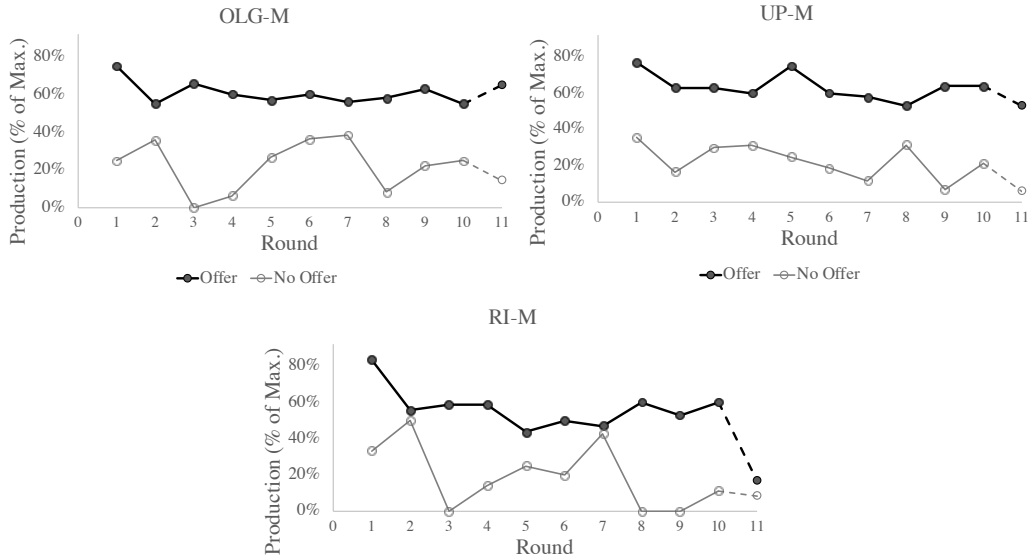
To understand the differing effects of money across games, we consider the strategic behavior in the Money treatments of each game. Recall that a monetary equilibrium strategy consists of two components. First, when a player has a token, she passes it along by offering the token in exchange for a unit of her consumption good. Second, when a token is offered to an agent, the agent accepts it in exchange for producing a unit. Figures 2 and 3 provide summary information regarding these components. Figure 2 illustrates the time path of token pass rates for the money treatments of each game. Notice in the figure that participants overwhelmingly passed available tokens when making a consumption request. In all treatments, participants passed tokens when available at least 80% of the time even in initial rounds. Further, in terminal period 11, the token pass rate is very close to 100% (100% in the OLG treatment, 90.5% in the UP treatment, and 85.7% in the R treatment). This is a third general finding.

Figure 2: Token Pass Rate



Finding 3. *In the money treatments of all games, players uniformly offer tokens in exchange for production.*

Figure 3: Production rates



Consider next players' responses to token offers. The three panels of Figure 3 illustrate production response rates for the money treatments of each game. Notice first that in all panels production rates both with and without token offers exhibit considerable variability, suggesting a randomness in responses that impedes the drawing of strong conclusions. Nevertheless, we also observe that in each game, money clearly matters in rounds 1-10 in the sense that the difference between production rates in response to and without token offers is persistent and in many instances quite large. In the OLG and UP treatments, the difference between production responses to and without token offers in round 11 remains at roughly the same levels as in the immediately preceding 2 to 3 rounds. In the RI game, however, the production response to token offers collapses in round 11, with the effect of driving down the overall production rate for the RI treatment with money as was previously observed in Figure 3.

To quantify how participant production rates respond whether a token is offered or not, we regress production decisions in the money treatments against a series of indicator variables D_j , $j \in \{OLG, UP, RI, OF\}$, where OF denotes the event that a token is offered. Specifically, we consider the regression equation (2),

$$y_{ijt} = \beta_0 + \beta_{OLG,OF} D_{OLG} D_{OF} + \beta_{UP,OF} D_{UP} D_{OF} + \beta_{RI,OF} D_{RI} D_{OF} + \beta_{UP} D_{UP} + \beta_{RI} D_{RI} + \varepsilon_j + u_{ijt} \quad (2)$$

where y_{ijt} is production decision (0 or 1) of subject i in group j in period t . As in equation (1) we cluster data by groups and use a robust (White sandwich) estimator to control for possible unspecified autocorrelation or heteroskedasticity.

Table 5: Production Rates, with and without Token Offers

Game	Offer	No Offer	Offer-No Offer
<i>Rounds 6-10</i>			
OLG-M	58.8%	26.2%	32.6***
UP-M	60.0%	18.8%	41.3***
RI-M	54.2%	16.2%	38.0***
<i>Rounds 11</i>			
OLG-M	65.5% ^{†††}	14.2%	51.2***
UP-M	52.6% ^{††}	5.9%	46.7***
RI-M	16.7%	8.3%	8.4

Key: [†]Reject the null hypothesis that mean production rates given an offer do not vary across the row treatment and RI-M. *Reject the null hypothesis that production rates with an offer do not differ from production rates without an offer.

Summary results for rounds 6-10, as well as for round 11, appear in Table 5.²¹ In the OLG treatment with money, over rounds 6-10, players produced in response to a token offer in 58.8% of instances and produced without a token offer in 26% of instances for an average difference of 32.6 percentage points. In round 11, the production response to a token offer increased to 65.5, and the production rate absent an offer fell to 14.2% for a net 51.2 percentage-point increase in production rates associated with the use of a token (difference significant at $p < .01$). In the UP treatment, over rounds 6-10, players produced in response to a token offer in 60% of instances and produced without a token offer in 18.8% of instances for a 41.2 percentage point increase in production rates associated with a token offer (difference significant at $p < .01$). In round 11, the production response to an offer fell slightly to 52.6%, but the production rate absent an offer fell still further to 5.9%, resulting in a 46.7 percentage-point production rate increase resulting from token offers (difference significant at $p < .01$), an increase very similar to that in the OLG treatment.

Finally, in the RI treatment with money, over rounds 6-10, players produced in response to a token offer in only 54.2% of instances and produced without a token offer in 16.2% of instances, yielding a 38 percentage-point increase in production

²¹As in Table 4, we present results only for rounds 6-10 for purposes of succinctness. Summary results for rounds 1-5, as well as primary regression results for all estimates, appear as Tables C5.1 and C5.1A, respectively, in Appendix C. For ease of interpretation, we report linear probability estimates. Logit estimates, reported as Table C5.2 and C5.2A in Appendix C, yield more or less identical results.

rates due to token offers (difference significant at $p < .01$). In round 11, however, the production response to token offers collapsed. The production rate following a token offer fell to 16.7%, while the production rate absent a token offer fell to 8.3%, for a statistically insignificant 8.4 percentage-point difference in production rates in response to and absent a token offer. We summarize these observations as the following fourth general finding.

***Finding 4.** In all treatments, production requests with token offers increase production rates over production requests without token offers by 30 to 40 percentage points in rounds 6-10. In the OLG and UP treatment, this difference increases to roughly 50 percentage points in terminal round 11. In the RI treatment, however, production responses to token offers collapse to a level that differs insignificantly from production rates without a token offer.*

6 Discussion: Strategic Considerations, Mistakes, or Indirect Reciprocity?

From the findings described in the previous section, we see that:

1. the introduction of money matters in all our setups, but
2. play fails to approach the efficient monetary equilibrium in all the games, and
3. in stark contrast to theory, money most consistently matters in the OLG game, a game with no monetary equilibrium.

In the UP game, players respond to token offers at roughly the same rate as in the OLG treatment, but overall production rates remain marginally lower in the UP treatment than in the OLG with money. For the non-monetary treatments, production is marginally higher in the UP game than in the OLG setting. Taken together, this means that the net effect from introducing money is large and highly significant in the OLG setting, but small and insignificant in rounds 6-10 of the UP game. For the UP game, the effect completely vanishes in round 11. In the RI game, production rates in the monetary treatment exceed those in the non-monetary treatment by roughly the same amount as observed in the OLG setup over rounds 6-10. However, players' responses to token offers collapse in round 11, causing production rates to also collapse.

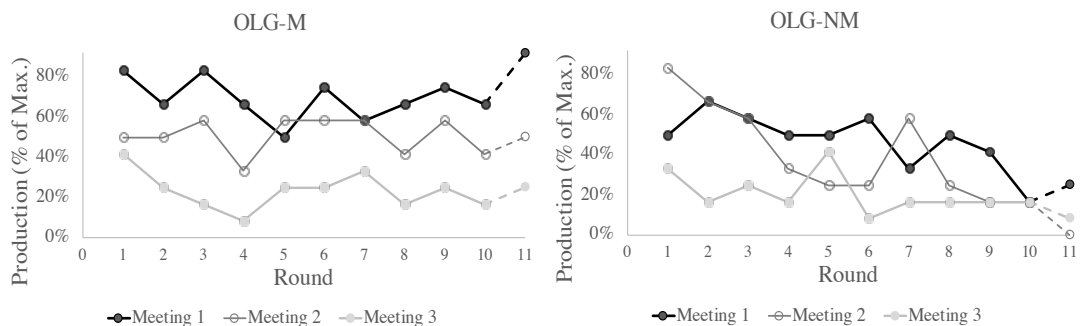
Viewed in light of predicted equilibrium outcomes, these findings raise a number of questions. First, why doesn't production collapse toward the unique equilibrium prediction in the OLG treatment with money? Second, given that players tend to use tokens in rounds 6-10 in the monetary UP and RI treatments, why don't outcomes gravitate toward the efficient monetary equilibrium? Third, in the UP

game, given that players respond strongly to token offers in the monetary treatment, why doesn't money matter more? Finally, fourth, why did players stop accepting tokens in the terminal round of the monetary RI treatment? These patterns were to a large extent surprising to us, and our experiment was not designed to isolate the factors driving these results. The discussion is therefore necessarily informal, as additional experiments are needed to evaluate the role of the potential explanations being put forward below.

6.1 Puzzle 1: Why is Money Used and Useful When it Shouldn't Be?

Consider first the persistently stable rates of production in the monetary OLG treatment. In itself, this could simply reflect a failure to understand equilibrium analysis, and there is ample evidence in the experimental literature that subjects often "fail" to backward induct. However, a number of factors suggest that there may be something more interesting going on. To begin with, the game being played is arguably very simple, and it seems hard to believe that player 3 would not be able to look forward and conclude that player 4 doesn't have any incentives to produce in exchange for a token in the final period when meeting player 2. Indeed, this view is highly consistent with the almost linearly decreasing production rates throughout rounds 1-11 of the associated nonmonetary treatment, which looks much like the subjects are learning to appreciate the strategic considerations and thereby converging to the unique equilibrium. Also inconsistent with simple misunderstanding is the 7.8 percentage-point production rate increase (to 55.6%) in round 11 of the monetary OLG treatment, where participants were rematched for a one-time interaction into groups with players they had never seen, and where the earnings consequences of decisions were tripled.

Figure 4: OLG Production rates



While the introduction of money does not have any effect on equilibrium outcomes (with standard preferences) because of the finite horizon, it does change the environment. With money, it is possible to make inferences about past behavior,

and the patterns in Figure 4 suggest that being able to make such inferences is important. Note that such differences are not only inconsistent with standard theory, but also with altruism. If altruism would be driving the results, there would be no reason for play to converge towards autarky when there is no money.

Given that there is repeated interaction in a group of four agents for the first ten rounds it is possible that (direct) reciprocal preferences (see Levine 1998) could be part of the explanation. Such an explanation, however, seems in direct contradiction with the spike of production in the one-shot round 11.

An alternative that appears consistent with our experimental results is *indirect reciprocity*. The notion of indirect reciprocity was first proposed by the evolutionary biologist R.D. Alexander (1987) to capture the propensity of humans to engage in costly pro-social activities that yield only abstract benefits. Unlike more standard notions of intra group cooperation, such as conditional cooperation or direct reciprocity, where an agent incurs costs to benefit a second agent (or group of agents) in light of the prospect of reciprocating beneficial actions by the second agent(s), indirect reciprocity is the decision by one agent to make a costly effort for a second agent based on whether or not that agent has previously assisted a third agent, with some expectation that they may similarly be rewarded for their decision in the future. Alexander argues that indirect reciprocity has evolutionary benefits. To the extent he is correct, some propensity toward indirect reciprocity may be hardwired into the decision-making process, at least for some participants.²² In the models considered in this paper, money serves as a record of previous cooperation that makes indirect reciprocity possible, even as agents fail to respond to the strategic structure of the game.²³

Further and critically, indirect reciprocity is to be distinguished from altruism. Although some unconditionally cooperative participants may incur a production cost to reward another player for choosing to produce even when there is no possibility of a subsequent reward, more generally, the percentage of participants willing to produce given a token moves directly with the likelihood of subsequently being compensated with the receipt of a unit. Production rates disaggregated by meeting number for the monetary OLG treatment, shown in the left panel of Figure 5, illustrate this. Although some variability exists across rounds, after the first four or five rounds, production rates stabilize at roughly 75% in the first meeting, 50% in the second meeting, and 25% in the third meeting. Most importantly, however, production does not decay over rounds because players, particularly those in meet-

²²Experiments, both in the laboratory and in the field suggest that indirect reciprocity can prominently affect group outcomes. See Seinen and Schram (2006), and van Apeldoorn and Schram (2016).

²³The idea that money facilitates indirect reciprocity is also interesting in light of Duffy and Puzzello (2014a). There, the authors observe higher levels of production in a monetary treatment despite the existence of a still more efficient non-monetary gift-giving equilibrium. Here we suggest that money provides a record of actions that facilitates indirect reciprocity, despite the fact that no monetary equilibrium exists in our finitely repeated OLG game.

ings 1 and 2, maintain high levels of production in light of the knowledge that the person for whom they have been asked to produce has also incurred production costs, and that there is some chance (albeit a decreasing one as the meetings in sequence progress) that they too will be compensated. In this way, only a relatively small percentage of altruistic (or perhaps confused) participants need to respond to an offer by producing in meeting 3 to sustain cooperation in the monetary OLG treatment. This contrasts sharply with the disaggregated production rates in the non-monetary OLG treatment, shown in the right panel of Figure 4, which, after starting at levels comparable to those observed in initial rounds of the monetary OLG treatment, decay steadily in meetings 1 and 2 as the rounds progress.

To sum up, while other factors such as a failure to backward induct or altruism could be a part of the picture, we believe that indirect reciprocity could be an important factor to explain how money facilitates cooperation despite a short finite horizon. An experimental treatment that could shed some further light on this would be to add a nonmonetary treatment of the OLG model in which trading histories are observable. Should indirect reciprocity be the driving force, one would expect that production rates would be at least as high in this treatment as in the monetary treatment. Otherwise, one would have to look at yet other alternatives, such as the possibility that the use of fiat money is so ubiquitous so as to make people naturally inclined to do so even when strategic consideration suggests they shouldn't.

6.2 Puzzle 2: Why doesn't Play Converge Towards the Efficient Monetary Equilibria when One Exists?

Obviously, theory doesn't have much to say about which equilibrium players should coordinate on. Hence, one could simply argue that at least some players are trying to coordinate on the autarky equilibrium, which explains the failure to coordinate on the efficient equilibrium. We can't completely rule this out, but it doesn't look like this can fully explain the patterns in the data. In particular, if players were drawn by equilibrium strategies, one would think that the most common outcome would be that they would either uniformly accept tokens for production or always reject tokens. This is not what happens. Equilibria involving mixed acceptances do exist, but they do seem rather fragile, so we don't believe this is what is going on.

Again, a plausible explanation seems to be that a subset of the participants are behaving in accordance to indirect reciprocity. Given the similarity with the OLG treatment, one would think that whatever motivates behavior in that game should be a factor also in the UP and RI models.²⁴ It would also be consistent with play ending up somewhere in between autarky and the monetary equilibrium.

²⁴The production rate sequences disaggregated by meeting number for the monetary treatments of the UP and RI models, shown as Figures C.1 and C.2 in Appendix C, follow patterns roughly similar to those in the monetary OLG treatment, albeit with some increased variability across rounds.

Table 6: OLG Production rates

Token Offer		No Token Offer				No Money					
Periods 1-5											
		P4				P4				P4	
		<i>Hawk</i>	<i>Dove</i>			<i>Hawk</i>	<i>Dove</i>			<i>Hawk</i>	<i>Dove</i>
P3	<i>Hawk</i>	20.0%	13.3%	P3	<i>Hawk</i>	33.3%	11.1%	P3	<i>Hawk</i>	13.3%	18.3%
	<i>Dove</i>	6.7%	60.0%		<i>Dove</i>	26.7%	28.9%		<i>Dove</i>	23.3%	45.0%
Periods 6-10											
		P4				P4				P4	
		<i>Hawk</i>	<i>Dove</i>			<i>Hawk</i>	<i>Dove</i>			<i>Hawk</i>	<i>Dove</i>
P3	<i>Hawk</i>	23.1%	15.4%	P3	<i>Hawk</i>	25.5%	19.1%	P3	<i>Hawk</i>	31.7%	16.7%
	<i>Dove</i>	38.5%	23.1%		<i>Dove</i>	21.3%	34.0%		<i>Dove</i>	30.0%	21.7%

Furthermore, if strategic considerations are the driver of behavior, then it must be that the coordination in the hawk-dove game depends on whether player 3 transfers a coin or not in the final meeting of the RI game. We can see no evidence of this in the data. To the contrary, as the summary of outcomes for the Hawk-Dove game, shown in Table 6, illustrates, in rounds 1-5 players coordinated on the Hawk-Dove outcome following a token offer in only 13.3% of games. This is just slightly higher than the 11.1% rate of coordination in the rounds where no token was offered and 5 percentage points lower than the incidence of Hawk-Dove outcomes in rounds 1-5 of the No Money RI treatment. Matters hardly improved in rounds 6-10, where players coordinated on the Hawk, Dove outcome following a token offer in 15.4% of instances, 3.7 percentage points below the 19.1% incidence of Hawk, Dove outcomes when no token was offered and 1.3 percentage points below the 16.7% incidence of Hawk-Dove outcomes in the No Money treatment. In fact, following the presentation of a token, players in position 3 were more compelled play Dove than Hawk, while those in position 4 were more compelled to play Hawk. In rounds 6-10, for example, following the presentation of a token, player 3 played Dove in 61.6% of instances, while player 4 played Hawk in 61.1% of instances. This compares to a 51.3% incidence of Dove play by player 3 when no token was offered, and a 46.8% incidence of Hawk play by player 4 in the same circumstance. None of these differences, however, are statistically significant, as can be seen in Tables C7.1 to C7.4 in Appendix C.

Hence, again we are left with a pattern that seems hard to explain convincingly from strategic considerations. Indirect reciprocity seems more consistent with our experimental findings, but, again, we did not design the experiments to isolate such behavior. Maybe accepting money could be a (culturally) hard-wired behavior given

the central role money plays in everyday life.

6.3 Puzzle 3: Why is Money Less Useful in the Treatments with Monetary Equilibria?

Our two remaining questions are (i), why isn't money more effective in the UP game, and; (ii) why does the use of money collapse in round 11 of the RI game? We think these issues are related and will therefore discuss them together. In each case, the experiments are telling us that money is more helpful in the OLG game than in a model where money in theory could be useful. While hard-wired behavior such as indirect reciprocity could explain the use of money under circumstances when standard theory predicts it shouldn't be useful, one would think that it would be helpful rather than harmful to have money circulate in a setup with a monetary equilibrium. After all, it seems that *some* players would respond to the strategic considerations and refuse to produce in exchange for a token in the OLG setup, whereas this unravelling would not occur in the other monetary treatments.

Consider first the UP game. Here, although players respond to token offers at roughly the same rate as in the monetary OLG treatment, overall production rates with money remain 6.1 percentage points lower in the UP treatment than in the OLG treatment and 7.8 percentage point higher in the nonmonetary UP treatment than in the OLG setting with no money. Although the effects in either direction are fairly small, the combined result is a highly significant 20 percentage-point production rate increase when money is introduced in the OLG model, compared to an insignificant 6 percentage-point difference in the UP model for rounds 6-10, with the round 11 difference across treatments growing to 44 percentage points in the OLG game and falling to 0 in the UP game.

One possibility is that the different way that decisions are elicited in the OLG and UP games may explain the differences observed across both the money and no money treatments of these games. Most prominently, the sequential decision structure of the OLG treatments facilitates learning by clarifying the consequences of decisions. This is in contrast to the UP treatments, where participants observe outcomes following their simultaneous selection of multiple possible contingencies. We were aware of this issue before the experiments were run, but we worried about participants being able to infer their place in the order if we performed the experiment truly sequentially.

Relatedly, the monetary OLG treatment also allows participants to condition their production decisions on their position in sequence, whereas in the UP treatment participants make a decision to respond to a token offer or not, independent of their position in sequence.²⁵ Thus, even with similar average token offer response propensities, production rates may be higher in the monetary OLG treatment both

²⁵Of course, from a strategic perspective, this is the very feature of the UP-M game that allows a monetary equilibrium to exist.

because a high percentage of UP treatment players may fail to appreciate even weakly dominant strategies (such as passing tokens when available) and because OLG treatment participants may be more likely to respond a token offer in the early meetings of a round than UP treatment players who submit token response decisions independent of their position in sequence.²⁶

Similarly, in the non-monetary treatments, the sequential decision structure of the OLG setup may more effectively convey the negative consequences of incurring a cost to produce a unit for another player in an obvious way than in the UP game, where simultaneous production decisions are followed by outcomes determined by a random ordering of players, a process which may slow the development of an appreciation for the costs of incurring unobservable production costs. While this is speculative, it seems worth the while for future research to investigate whether the straightforward sequential structure of the OLG game could somehow facilitate indirect reciprocity and/or improve the understanding of the costs of producing for another when that decision goes unseen in the OLG non-monetary treatment.

Consider finally the collapse in production response to token offers in round 11 of the RI treatment. At first, one may think that this is actually consistent with theory, as the monetary equilibrium requires coordination on equilibria that depend on whether or not player 3 has a token to offer or not. This seems pretty hard to achieve in a one-shot interaction, whereas having 10 rounds to learn to coordinate seems more hopeful. However, as we already discussed, the raw data on how the Hawk-Dove game is played don't support the hypothesis that play in the Hawk-Dove game is contingent on token offers.

Another natural hypothesis is that simple chance explains the precipitous drop in responses to token offers in the terminal round. In this round, only 12 of the 36 participants in the monetary RI treatment had an opportunity to produce in response to a token offer, and only 2 accepted the offer.²⁷ In principle, the 10 participants who chose to not produce might have been an ex-post non representative subset of participants in the cohort who were substantially less inclined to respond to a token offer than the others.²⁸ Again the data, however, do little to support

²⁶A review of token pass rates across meetings suggests that a higher incidence of UP treatment players failing to pass available tokens is the primary reason for the comparatively lower production rates in that treatment. In the first two meetings of the OLG treatment with money, players 1 and 2 failed to offer available tokens in only 2.2% of instances (five of 225). In contrast, in the first two meetings of the monetary UP treatment players 1 and 2 failed to offer tokens in 10.8% of possible instances (23 of 213) available). That said, it is also the case that token offers in the first meeting of the OLG treatment were 5.8 percentage points more likely to be accepted than in the UP treatment (73.2% versus 67.5%). This is consistent with participants in the monetary OLG treatment conditioning their response on their place in sequence.

²⁷In round 11, two of the 10 token offers in the first meeting were accepted. Both tokens were offered in the second meeting, but neither was accepted. One player, however, did produce without an offer. In total, only three of the 24 possible units were produced.

²⁸Had these 10 players been ordered first or fourth in sequence, and had the remaining players responded to token offers, the period 11 production rate might have been as high as 100%.

such a hypothesis. Although the 10 participants who rejected offers in round 11 did have a record of being less inclined to produce in than the other participants in the treatment, the difference is both relatively small and insignificantly different from zero. For example, over rounds 6-10 those participants who rejected token offers in round 11 had rejected token offers in 39.1% of instances, compared to the other participants in the treatment cohort, who rejected token offers in 29.9% of instances, a statistically insignificant 9.2 percentage-point difference.²⁹

An alternative and possibly more appealing hypothesis is that the combination of the reduced number of meetings involving production decisions in the monetary RI treatment and the utter incapacity of participants to use tokens to solve the coordination problem in the meeting 3 Hawk-Dove game led participants following the reshuffling of players, and the tripling of payoffs in round 11, to conclude that there was little possible benefit for player 3 to collect a token, making player 2 also less inclined to produce. This could potentially be tested by scaling the payoffs or increasing the number of meetings so as to keep the costs and benefits the same as in the other treatments.

7 Concluding Remarks

In recent years, considerable attention has been given to the use of experimental methods for evaluating the behavioral relevance of micro-founded models of fiat money. In this paper, we point out an important procedural issue generic to the bulk of these experiments. Specifically, in an effort of implement the infinite horizon routinely assumed in the theoretical literature, experimentalists have used a probabilistic stopping rule. Conceptually, this is problematic because laboratory sessions, by needs, cannot continue indefinitely. It is also a problem procedurally because a considerable body of behavioral evidence suggests that laboratory subjects do not view the probabilistic stopping rules typically used to induce an infinitely repeated framework in a manner consistent with the theoretic response to a discount factor in an infinitely repeated context. For this reason, results of laboratory implementations of infinitely repeated models suggesting that the availability of a fiat currency yields more efficient outcomes must then be a consequence disequilibrium behavior, perhaps induced by participants incorrectly interpreting stopping probabilities, or some other feature of the game that induces adoption of a fiat currency despite the existence of a finite horizon.

Infinite repetition, however, is not a necessary feature of micro-founded models in which the addition of a fiat currency can improve efficiency as an equilibrium phenomenon; uncertainty of one's position in sequence (random matching); the presence of multi-equilibria in a final stage game (role identification) can also support

²⁹We generate the reported percentages by regressing offer rejections in rounds 1-10 against an indicator variable for participants who rejected offers in round 11. Reported results appear as Table C6 in unpublished data Appendix C.

monetary equilibria. This paper develops a pair of simple finite horizon models that include these features and which feature monetary equilibria. We evaluate the behavioral results of these games in light of a finite horizon overlapping generations framework where no monetary equilibrium exists. Experimental results suggest that neither the random matching nor role identification games induce participants to converge on an efficient monetary equilibrium. In fact, we find that the presence of a fiat currency did no more to promote efficiency in either of these games than was the case in the finitely repeated overlapping generations game. To the contrary, money consistently mattered the most in the overlapping generations game.

Thus, results indicate that players tend to adopt a fiat money, even when it is not an equilibrium strategy, suggesting that features of the game other than the existence of an equilibrium, drive the use of a fiat money in these laboratory games. For future experimental work investigating the capacity of a fiat currency to generate a monetary equilibrium, it would seem useful to explore more fully the factors that behaviorally affect the adoption of a monetary equilibrium even when such a strategy is not part of an analytic equilibrium. In particular, we suggest here that indirect reciprocity provides one appealing explanation for the adoption and stability of a fiat money. Experiments explicitly designed to isolate the strength and resilience of indirect reciprocity seen as a behavioral factor driving the adoption of a fiat money seem especially promising.

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Appendix A

This appendix overviews two games not included in the text. The first game sketches out the structure of the random matching game along the lines of Kiyotaki and Wright (1993). While an infinite horizon is an essential part a monetary equilibrium in the case of a pure fiat currency, a finite horizon version can sustain use of money for transactions purposes if there is a small dividend paid . The second game sketches out a public goods game in which players can accept or pass a token in exchange for a binding commitment to contribute to a costly public good. This game also has an efficient monetary equilibrium for yet a different reason. Money can change the sequential structure from a simultaneous move game into making a player a Stackelberg leader.

Game A1: Random Matching

Suppose that there are n agents labeled by $i = 1, \dots, n$. Agents are randomly matched in each period, and we let α be the uniform matching probability for every pair (i, j) . Conditional on a match, with probability $\sigma \leq 1/2$ there is a single coincidence meeting in which i can produce the good j likes to consume and with probability σ agent j can produce the good that i consumes that period. For simplicity, double coincidence meetings in which i can produce the good that j consumes and j can produce the good that i consumes can easily be allowed for, but they are ruled out here for simplicity of notation. Again, let the utility from consumption be u and

the cost of production be $c < u$. We assume that time is discrete with an infinite horizon and that agents discount the future in accordance with β .³⁰

The Nonmonetary Economy

If trading histories are observable and agents are patient enough it is possible to support gift-giving equilibria using trigger strategies much the same way as in the overlapping generations model. In fact, the conditions for when a gift-giving equilibrium exists coincide with those for the existence of a monetary equilibrium, so money is not essential in this case. In fact, Araujo (2004) demonstrates that given any giving n there exists some $\beta^*(n)$ such that efficient equilibria without money exist for $\beta \geq \beta^*(n)$ using contagion strategies similar to Kandori (1994). However, the larger is n , the harder it is to support efficiency. This is because punishments are triggered gradually with unobservable histories. Immediately after a deviation it is only two agents who are aware of the deviation. Given that they implement the punishment phase, in the second period after the deviation at most four agents are aware of the deviation and so on. If n is large, it therefore takes a long time until a significant proportion of the players are playing in accordance to the punishment phase, which makes unilateral deviations relatively more appealing.

The Monetary Economy

We now endow $m < n$ agents with an indivisible asset. Agents can hold at most one unit of the asset, and we assume that the agent holding the asset commits to an offer to the potential producer, which specifies whether or not the asset will be transferred conditional on the good being produced. We now refer to the indivisible object as an asset because we allow for a dividend (or cost) stream $\rho \neq 0$ to the agent holding the object. Fiat money is the special case with the dividend being zero, a positive dividend would correspond with using a real asset, and a negative dividend could be interpreted as storage or maintenance costs. However, whether $\rho = 0$ or not, we refer to an equilibrium in which the asset is traded for transactions purposes as a monetary equilibrium. We don't allow the buyer to offer lotteries as in Berentsen et al. (2002), which makes a difference when ρ is large enough.

In contrast to the contagion equilibrium, the conditions for when a non-autarky outcome can be sustained by trade in the asset are independent of n provided that the probability of a single coincidence meeting is held fixed. To see this, consider the following strategy profile. Every consumer holding an asset proposes that the

³⁰Note that we depart from much of the existing literature by making it a random draw whether there is a single coincidence meeting. This is because, with finite numbers and constant costs and preferences beliefs over which types of agents have matched with whom depend the matching history of the agents. This is relevant for the characterization of monetary equilibria, because beliefs over matching histories translate into beliefs over which agents hold money, which clearly is payoff relevant for the individual. Araujo (2004) uses the same simplification in his finite version of Kiyotaki and Wright (1998) for the exact same reason.

producer produces in exchange for the asset. We therefore suppose that the asset is always offered and accepted when possible, and let V_1 be the value of holding the asset, and V_0 be the value of holding no asset. Then, the value from holding the asset is

$$V_1 = \rho + \alpha\sigma \frac{n-m}{n} [u + \beta(V_0 - V_1)] + \beta V_1, \quad (3)$$

where the dividend is paid before trade occurs. The value of holding no money is

$$V_0 = \alpha\sigma \frac{m}{n} [-c + \beta(V_1 - V_0)] + \beta V_0, \quad (4)$$

where to make it incentive compatible to accept money

$$\beta(V_1 - V_0) \geq c. \quad (5)$$

Additionally, it must be incentive compatible to give up the asset for a consumption opportunity, which requires that

$$u \geq \beta(V_1 - V_0). \quad (6)$$

Taking the difference between (3) and (4), we have that,

$$\beta(V_1 - V_0) = \frac{\beta}{1 - \beta(1 - \alpha\sigma)} \left[\rho + \alpha\sigma \left[\frac{n-m}{n}u + \frac{m}{n}c \right] \right], \quad (7)$$

so (5) and (6) are satisfied if

$$\begin{aligned} \beta \left[\rho + \alpha\sigma \left[\frac{n-m}{n}(u-c) \right] \right] &\geq (1-\beta)c \\ \beta \left[\rho - \alpha\sigma \left[\frac{m}{n}(u-c) \right] \right] &\leq (1-\beta)u. \end{aligned} \quad (8)$$

From (8), we see that if $\rho \geq 0$, but not too large, then trade can always be achieved for β large enough. If $\rho < 0$, then α and σ must also be sufficiently large, which reflects that the cost of holding the asset is then proportional expected length until the next trade opportunity. Moreover, if n and m both double the condition in (8) is unchanged, so, unlike the contagion equilibrium condition, the size of the economy doesn't affect restrictions on $u, c, \alpha, \beta, \sigma$ and m/n that are needed for a monetary equilibrium to exist. Hence, there is a parameter range for which money is essential provided that transactions cannot be recorded. In addition to the stationary monetary equilibrium, there is also always a stationary non-monetary equilibrium provided that ρ is not too large, as well as a stationary mixed strategy equilibrium where money is accepted with a probability that makes agents indifferent between accepting and rejecting money. However, Shevchenko and Wright (2004) argue that the mixed equilibrium is non-robust.

There are also non-stationary monetary equilibria. To construct such equilibria is beyond the scope of this paper but could possibly be relevant for interpreting

experimental results. See Kehoe et al. (1993), Renero (1998), and Wright (1994) for analysis of non stationary equilibria in the context monetary models similar to the one in this paper.

Finally, it is also worth noting that when money is valued because of its role facilitating transactions, it is a *rational bubble* in the sense of Tirole (1985). That is, the valuation is exceeding the fundamental value (zero in the case of fiat money) because of the expectation that other agents will accept it in the future. However, in economies with frictions, bubbles can be welfare improving, and the case with fiat money in random matching is one of the cleanest examples of this.

Finite Truncations of the Game

Again, assuming that $\rho \leq 0$, monetary equilibria fail to exist in the game with a finite horizon for exactly the same reasons discussed in the context of the overlapping generations model. This is true with random terminations too unless one can commit to continuing the experiment forever if needed be, which of course is impossible.

If $\rho > 0$, there is still no incentive to accept money in the last period. But, if there are T periods to go and an agent accepts a coin and then holds it to the last period, this is better than never producing again, provided that

$$-c + \beta \frac{1 - \beta^T}{1 - \beta} \rho \geq 0.$$

Hence, if β is large and T is long enough the only issue in terms of whether monetary equilibria exist is whether the potential consumer is willing to trade money for the consumption good, which will be the case if

$$u > \beta \frac{1 - \beta^T}{1 - \beta} \rho \geq c.$$

There are thus monetary equilibria where for some time money circulates, before being held purely for the dividend toward the end of the game. Hence, a simple fix to finite horizon experimental designs is to add a positive dividend which, in theory, can be arbitrarily small, in order to avoid undesirable end game effects. This is not exactly the same, but related to allowing the “experimental money” to be “backed by the experimenter,” so that it is traded in the final period, as in Berentsen et al. (2017). The one downside is that the experiments are no longer about pure fiat money.

Game A2: Contributing To Public Goods

There are three players labeled $i = 1, 2, 3$. Players $i = 1, 2$ can invest in a public good, which we model as a binary choice, whereas player 3 makes no decisions in the non-monetary economy. We write w for the action where a player works to invest

in the public good and we denote by s the action where a player shirks and doesn't contribute. We assume the payoffs as given as

$$\begin{array}{cc}
 & w & s \\
 w & G - c_1, G - c_2, G & g - c_1, g, g \\
 s & g, g - c_2, g & 0, 0, 0
 \end{array} . \tag{9}$$

An interpretation is that G is the level of the public good that is achieved if players 1 and 2 both work to invest, g is the level achieved if only one player works, and c_i is the cost of working for $i = 1, 2$.

Usually parameters in discrete public good games are set so as to generate a prisoner's dilemma, but this would not work for us as the sequential structure would then be irrelevant. We therefore set parameters such that (w, w) is the efficient outcome and (s, s) is the unique Nash, but where player 2 would have an incentive to work if player 2 could commit to working. That is, we assume that

$$G - c_1 < g < G - c_2, \tag{10}$$

to ensure that player 1 shirks if player 2 works and that player 2 wants to work if player 1 works. Additionally, we assume that

$$g - c_2 < 0, \tag{11}$$

which implies that player 2 shirks if player 1 shirks. Combining (10) and (11) we obtain

$$g - c_1 < g - c_2 < 0. \tag{12}$$

Hence, always shirking is a dominant strategy for player 1 in the simultaneous move normal form game depicted in (9). The best reply for player 2 is to work if and only if player 1 works, so the unique Nash equilibrium is (s, s) . To avoid trivialities, we also assume that $g > 0$ and that

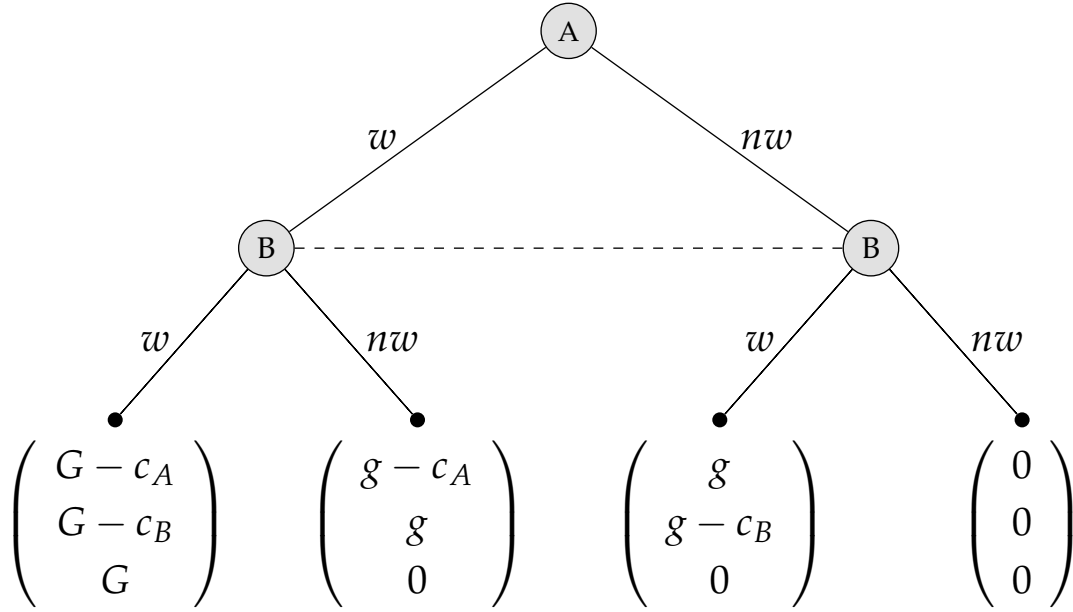
$$G - c_1 > 0, \tag{13}$$

which guarantees that (w, w) Pareto dominates (s, s) . The inequality in (13) also has the implication that the unique subgame perfect equilibrium in a sequential game where player 1 moves before player 2 is for 2 to work if and only if 1 works and for 1 to work, which would implement the desirable outcome (w, w) .

The Nonmonetary Equilibrium

We assume that there are two pairwise meetings. In the first period, players 1 and 3 meet. In this meeting, player 1 can work to produce some public good and player 3 does nothing in the non-monetary economy. In the second period, players 1 and 2 meet, and then it is player 2 who can work to produce some public good, whereas player 1 has no available action in the model without money. Player 2 cannot

Figure 5: Sequential game



observe the action taken by player 1 in the first period, so the normal form of the game is that in (9), and the unique non-monetary equilibrium is thus for players 1 and 2 to shirk. It should be noted that adding cheap talk in stage 2 does not have an effect on the equilibrium outcome, as player 1 would always use a message that would make player 2 more likely to work, regardless of the action taken in period 1.

The Monetary Economy

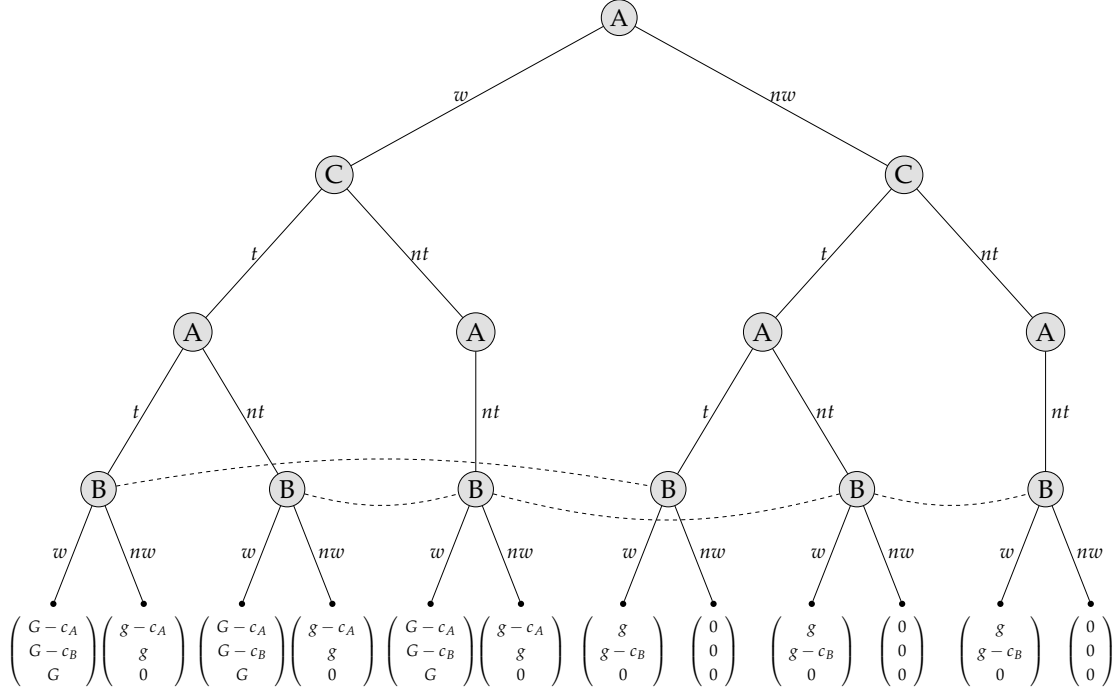
We now endow player 3 with a unit of an object that no agent can derive any consumption utility from, which we refer to as *money*. For simplicity, we will treat money as indivisible, but the example trivially extends to the case with divisible money. What is important, however, is the timing that allows player 3 to have some commitment power.

In the beginning of period 1, player 3 makes a take-it-or-leave-it offer, which specifies an action a_1 in $\{w, s\}$ for player 1 and whether the unit of money is transferred from 3 to 1. Then player 1 either accepts or rejects. If the offer is accepted both parties are bound to execute their part of the contract, otherwise the money doesn't change hands and (without loss of generality) player 1 takes the action s .³¹ Then, in the second period, player 1 can transfer a unit of money to player 2 if

³¹For the same reasons as (s, s) is the only equilibrium outcome in the non-monetary model, there is no equilibrium in the monetary economy where player 1 works without being able to transfer money in the second period.

holding money before player 2 takes an action a_2 in $\{w, s\}$. Notice that player 2 can only directly observe whether 1 holds a unit or money, and not the investment decision. The extensive form of the game is sketched in Figure 6 below:

Figure 6: Sequential game



We first note that, just like in most microfounded models of fiat money, there exists equilibria in which money is not valued. This is because if player 2 shirks regardless of whether player 1 has money or not, then player 3 may always (or never) hand the coin over to player 1. Assuming player 2 has pessimistic beliefs and thinks that player 1 shirked off the equilibrium path, player 2 is behaving sequentially rationally. Hence, the strategies described together with such pessimistic beliefs constitutes a perfect Bayesian Nash equilibrium. In terms of the variables that the players care about, such an equilibrium replicates the nonmonetary equilibrium.

There is also an equilibrium in which money is valued. Assume that:

- player 3 offers to hand over the coin if and only if 1 works;
- player 1 accepts the offer;
- player 1 hands over the unit of money to player 2 whenever possible.

Then, both information sets for player 2 are reached and the unique beliefs consistent with Bayes rule are that player 1 worked for sure when the coin is transferred to player 2, and that having no coin is evidence for not working. Hence, the

best response by player 2 given the unique consistent beliefs corresponding to these strategies by players 1 and 3 is to also work as $g < G - c_2$. Moreover, under the assumption that player 3 provides the coin if and only if player 1 works and that player 2 works if and only if player 1 pays her to do so with the (intrinsically useless) unit of money, working is a best response for player 1. Finally, player 3 has a strict incentive to provide the money if player 1 works in return for the money, and therefore has no profitable deviation. Hence, this is a perfect Bayesian equilibrium that generates an outcome that Pareto dominates the non-monetary equilibrium.³²

Notice that the example is a simple illustration of money being a substitute to record-keeping as stressed by Kocherlakota (1998) and Wallace (1980). If there would be a record of player 1 working in period 1, we could just forget about money because incentives (with or without money) would be captured by the sequential game in (5). In this example, there is a monetary equilibrium that perfectly replicates this outcome when there is no record keeping, and this is most easily understood from observing that if money is evidence of working, the incentives for the two potential investors is the same as in (5) (and that it is a best reply for the money holder to hand over the money if and only if player 1 works).

³²The example may appear non-robust as it relies on the player with money to have no incentive to hand over the money when player 1 shirks, which in turn requires that the player is being made no better off when the public good is partially provided compared with no provision at all. This, however, can be fixed by changing the game so that player 3 can extract some of the surplus from player 1. For example, letting the player with money make a “take it or leave it offer” would allow us to change preferences so that the equilibrium would survive even if all players are strictly better off when the project is partially completed.