Introducing New Forms of Digital Money: Evidence from the Laboratory*

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Abstract

Central banks may soon issue currencies that are entirely digital (CBDCs) and possibly interest-bearing. A strategic analytical framework is used to investigate this innovation in the laboratory, contrasting a traditional "plain" tokens baseline to treatments with "sophisticated" interest-bearing tokens. This theoretically beneficial innovation precluded the emergence of a stable monetary system, reducing trade and welfare. Similar problems emerged when sophisticated tokens complemented or replaced plain tokens. This evidence underscores the advantages of combining theoretical with experimental investigation to guide payments systems innovation and policy design.

Keywords: digital currency, endogenous institutions, repeated games.
JEL codes: C70, C90, E04, E05

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1 Introduction

Many central banks are considering issuing currency in an entirely digital form, known as CBDC (Boar et al., 2020). The goal is to replace or complement coins and banknotes—the sovereign monetary instruments that currently support retail payments (Camera, 2017). An intriguing feature of proposed CBDCs is the possibility of yielding negative or positive interest (Cœuré and Loh, 2018). This would mark a sharp departure from the Central Bank currencies we are used to, which historically carried no interest.[1] The possible ramifications of issuing an interest-bearing digital currency have not been systematically studied, and several questions remain open. In particular: Would their introduction affect the stability and performance of the currency system? What problems might emerge that standard theory does not foresee?

This study documents outcomes observed in laboratory economies where a "sophisticated" interest-bearing token replaced or complemented a "plain" token. Both instruments are peer-to-peer, with the former representing a CBDC and the latter a traditional Central Bank currency instrument. The design leverages the strategic analytical framework developed in Camera and Casari (2014), which captures general operating principles underlying monetary mod-

[1] Central Bank currency should not be confused with bank deposits, which are denominated in the same unit but typically carry an interest. Unlike Central Bank currencies, deposits are (i) private forms of money representing a claim on private debt not on the Central Bank, (ii) cannot be exchanged peer-to-peer because the exchange of deposits is intermediated, and (iii) support wholesale payments, while cash is primarily used for retail payments. An interest-paying sovereign currency could improve business cycles stabilization and, if issued to substitute cash, could remove the zero lower bound constraint on nominal interest rates (e.g., Bordo and Levin, 2017). Other reasons motivate the interest in CBDCs, not just the possibility of paying an interest. A CBDC could raise payments systems' efficiency by reducing the costly layers of financial institutions that support the processing and settlement of electronic payments. It could also improve the speed and efficacy of intervention through the monetary transmission channel. See for instance Ali et al. (2014); Broadbent (2016); Skingsley (2016).

els, easily adapts to experimental investigation, and has a replicable baseline performance (Bigoni et al., 2020).

The design involves economies consisting of eight individuals who interact in random pairs. In each pair one person can produce a consumption good for the other. Incentives to produce exist because consumption benefits dominate production costs and economic roles alternate over time, indefinitely. According to standard theory, these economies can support the intertemporal exchange of goods. Intertemporal exchange is socially efficient, but Pareto-inferior equilibria also exist, with partial or even no production at all. To facilitate efficient play, the economies are endowed with a fixed supply of tokens with no intrinsic or redemption value, and no link to outside currencies. I call these tokens "plain." If participants spontaneously trade production for a token, then a monetary system emerges in which tokens acquire value as payment instruments akin to a fiat currency.

This baseline condition is contrasted to treatments where tokens are more "sophisticated" in that they can yield small payoffs, positive or negative (a CBDC). That is, now we have positive or negative interest-bearing tokens. Several economic layouts are studied: economies with just one type of token, with two types of tokens, or where the economies start with plain tokens and then switch to sophisticated ones. By design, a strategy of monetary trade is sufficient to support efficient play in all treatments, though it is not necessary. That is to say, the use of tokens as a monetary instrument is entirely endogenous. Theoretically, making tokens interest-bearing should not degrade economic performance and, in fact, a positive interest should make tokens more attractive, facilitating the emergence of a monetary system. This and other hypotheses are tested with the data collected in the laboratory.

The analysis reveals that moving away from zero-interest tokens stunted the spontaneous development of a monetary system, preventing coordination on efficient play and lowering payoffs. This is not what standard theory would predict. To explain, all treatments reveal a strongly positive association between the frequency of monetary trade and realized efficiency. When a monetary system did not develop, or was poorly functioning, participants simply did not produce for others—which corroborates earlier experimental findings (Camera et al., 2013). A novel result is that while participants learned to trade by exchanging plain tokens, this did not occur with sophisticated tokens. Giving tokens a small positive interest shifted subjects' focus away from trying to attain large long-run payoffs by trading tokens, to securing low but predictable gains by hoarding tokens. This myopic behavior created illiquidity, preventing tokens' circulation and the development of a viable monetary system. Instead, giving tokens a small negative yield sharply reduced their acceptability and, hence, their usefulness as payment instruments.

This study makes two broad contributions. From a substantive perspective, it demonstrates that theoretically beneficial institutions may prove to be empirically harmful. The main message is that the laboratory economies performed best in a zero-interest rate environment. This provides useful information for Central Banks considering digital currencies with an interest bearing mechanism that is under their control. The experiment suggests that a currency instrument performs better when it is unencumbered by valuation aspects that go beyond the means-of-payments role. The cash flows granted by interest-bearing tokens distorted decision-making in the laboratory economies, fostering myopic conduct that precluded a currency system from emerging.

From a methodological perspective, the study brings to light the advantage of combining theoretical with experimental investigation to guide planning and decisions of policymakers (Smith, 1994). The experiment suggests that Central Banks pursuing currency innovation can gain valuable insights from studying economic behavior in laboratory economies. In this manner, the study contributes to a growing body of knowledge showing that the exploration of behavioral angles can improve overall policy assessment (Armantier and Holt, 2019; Duffy and Heinemann, 2020; Kryvtsov and Petersen, 2020). This does not imply that one should mechanically extrapolate from the experimental results policy recommendations applicable to field economies. Laboratory economies are not designed to be exact replicas of field economies, nor is the theory on which they are based, so elements crucial to calibrate a specific field situation may be missing. For instance, consider the possible use of interest-rate bearing CBDCs to stabilize business cycles. The naturally occurring price and income dynamics of field economics are not present in the laboratory economies studied here. This precludes an inflation-output trade-off to arise in the experiment—the traditional theoretical channel motivating interest-rate policy interventions. It is entirely possible that a richer design accounting for inflation-output trade-offs could make an interest-paying CBDC superior to a traditional "barren" currency instrument.

The study proceeds by situating the experiment in the extant literature (Section 2), discussing the design (Section 3) and providing a theoretical reference (Section 4). Results from the analysis of the experimental data are in Section 5, while Section 6 offers some final considerations.

2 Contribution to the experimental literature

One can classify existing designs of laboratory monetary economies based on whether monetary trade is taken as a primitive or not, and what objects can serve as a currency instrument; see Table 1. The primary focus has been studying traditional fiat monetary systems and commodity money. This project widens the focus to study the performance of possible alternatives to traditional currency instruments—a currently hot topic for which Central Banks have obvious data limitations.

In early experiments, monetary trade was taken as a primitive, meaning that participants *must* trade with a pre-defined currency instrument to earn income (e.g., Marimon and Sunder, 1993). Camera and Casari (2014) and Camera et al. (2013) innovated by proposing a design based on a game-theoretic framework in which monetary trade emerges spontaneously and is neither imposed nor needed to maximize payoffs. The present study builds on this second strand of literature by considering digital tokens that are more sophisticated than traditional fiat currency instruments, i.e., the intrinsically useless objects that are the standard theme of recent experiments (Duffy and Puzzello, 2014; Huber et al., 2014; Hirota et al., 2020).

Table 1: Contribution to the experimental literature on money.

	Monetary trade is externally imposed	Monetary trade emerges spontaneously
Plain tokens, goods	✓	✓
Sophisticated tokens	✓	unexplored

To explain, this study is part of a wider research agenda that investigates possible links between the development of monetary systems, market organization, and economic development. In particular, it is related to three recent articles that study how monetary systems affect the endogenous size of trading groups (Bigoni et al., 2019), the performance of reputational systems relative to monetary systems (Bigoni et al., 2020), and the competition between two trading systems, asynchronous monetary and synchronous non-monetary (Camera et al., 2020).[2] The present design pushes this research frontier forward by focusing on the impact of currency innovation on economic organization. The experiment introduces tokens that are more sophisticated than traditional fiat instruments, and in particular can yield a benefit that makes them theoretically preferable to traditional tokens. However, monetary trade is not imposed on individuals because there are alternatives to monetary exchange. A few experiments exists that are related to this theme of currency innovation, but they all assume away possible alternatives to monetary exchange. In Camera et al. (2003), buyers must choose between spending cash or a dividend-bearing perpetuity, while in Camera et al. (2016) traders must choose between a plain cash instrument or a better-performing electronic money, which is also true in Arifovic et al. (2019). The advantage of our design is it neither takes monetary exchange as a primitive nor imposes it as a pre-requisite for income-maximization. Monetary exchange supports maximum welfare but unnecessary to attain it because alternative non-monetary strategies exist that support efficient play. The following section clarifies how this is done.

3 Design of the experiment

Monetary theory stipulates that rational individuals choose to organize their economic activities to maximize the possible gains from trade. The experi-

[2]A main difference between commodity-based and token-based currency systems is that the former crowds out consumption (commodities serving the role of money cannot be consumed or used in production) while the latter does not (tokens are symbolic objects without alternative practical uses). Object-specific costs (holding, exchange or transportation costs) do not alter this consideration.

mental design reflects this principle and makes explicit the trading process.

The model is an adaptation of the one in Camera and Casari (2014). The economy consists of eight players who can trade objects for an indefinite number of rounds. Half are consumers, half are producers, and everyone switches role in every round as in a Turnpike (Townsend, 1980). In the baseline treatment, at the start of the economy every initial consumer is endowed with one plain "token." A token is a riskless electronic object that carries no interest and can be exchanged peer-to-peer. Tokens are indivisible, have no reference to outside currencies, cannot be redeemed for points or cash, and cannot be disposed of. Seen this way, tokens represent a stable supply of four units of a traditional Central Bank currency. Subjects are completely free to use or ignore tokens so that whether or not tokens circulate and become a valuable currency in the experiment is entirely endogenous. This is explained below.

A round of play. All interaction is in random producer-consumer pairs. In each round, every pair faces the game in Table 2. The producer is endowed with a good that both players benefit from eating: $d = 6$ points for the producer and $g = 15$ for the consumer. The producer determines who gets the good, and so has the full power to decide size and distribution of earnings in the pair. We say that there is *cooperation* if the consumer eats the good, and *defection* otherwise.

Table 2 illustrates which outcome occurs as a function of the actions taken in the pair. The producer can always transfer the good to his counterpart (C for "cooperate"), or eat it (D for "defect"); if the consumer has tokens, the producer can also offer to exchange the good for one token (sell). Consumers who have tokens can offer one for the producer's good (spend) or take no action (idle). Consumers without tokens have no action to take so the outcome simply depends on the producers D or C choice (shaded cells). The possession of tokens is disclosed to counterparts, but not the exact amount, to preclude identification and reputation-building.

Players make simultaneous choices—so they cannot signal cooperative intentions by offering or requesting tokens. Token exchange is *peer-to-peer* and *quid-pro-quo*. That is, no intermediary is needed to settle a trade, and exchange takes the form of a direct mechanism in which each pair of choices leads to a unique outcome. If choices are mutually compatible, then good and token change hands, and otherwise players keep their inventory.[3] Token holdings are unrestricted, so a subject can hold as little as zero and at most four tokens (the entire supply).

Table 2: The stage game

		Producer		
		D	C	Sell
Consumer	Idle	$3, 6$	$15, 0$	$3, 6$
	Spend	$3, 6$	Ⓣ $15, 0$	Ⓣ $15, 0$

Notes: Payoffs to Consumer, Producer, in points. Ⓣ indicates the transfer of a token from consumer to producer. The table depicts the game when the consumer has some token(s). The shaded cells refer to the restricted game, when the consumer has no token. The cell corresponding to Sell and Spend uniquely identifies a monetary trade outcome. Neutral language identified choices in the experiment (see Instructions in Appendix B).

A consumer who exits the meeting without the good earns $d - l = 3$ points,

[3]Limiting the exchange to one token per encounter simplifies subjects' cognitive task and fixes the price of tokens, removing speculative motives for exchange. Producers can prevent a token transfer by choosing D, which matters in the treatment where holding tokens creates losses.

while a producer in a similar situation earns $a = 0$ points. In the experiment 1 point = USD 0.15 so total earnings in a pair are either 15 or 9 points, depending on who consumes the good (consumer or producer). It follows that producers can create a 6-points surplus by transferring their endowment to consumers. Token exchange is unnecessary to create this surplus because the distribution of tokens in the pair neither affects the payoff matrix, nor prevents a cooperative action. Given the payoff structure, self-interested producers must have a prospect of future consumption to be willing to give up their endowment. This dynamic prospect is discussed next.

Supergame and session. An economy lasts 16 rounds plus an uncertain number of additional rounds. From round 16, at the end of each round there is probability $\beta = 0.75$ of another round, and a 25% probability of the economy ending, using a computer's random draw from a uniform probability distribution. The initial 16 rounds ensure a basic common experience across treatments and sessions, while the random termination prevents the end-of-game effects operative under deterministic ending rules (Roth and Murnighan, 1978). We refer to an uncertain sequence of 16+ rounds as a supergame.

At the start of each round, players change roles and are randomly rematched with uniform probability. This makes them "strangers" because they cannot communicate with each other, identify counterparts and scrutinize their past actions. This precludes reputation or reciprocity mechanisms.[4] At the end of the round, players see the outcome in their pair and the total number of cooperative outcomes in the economy.

Each session includes 24 players arranged in three distinct economies, which

[4]This restriction is standard in the theory of money, introduced by assuming infinite populations and private histories. For a conceptual discussion see the model economies in Lucas (1984) and Townsend (1980); for a technical discussion see Kocherlakota 1998.

start and end simultaneously. When they end, three new economies are created. This process is repeated five times, rematching session participants into new economies so that no-one can meet counterparts from a previous economy. This minimizes dynamic spillover effects, and is disclosed to subjects. Overall, a session generates data for 15 economies, with each subject participating in five different economies.

Treatments. The payoff structure in Table 2 is common to all treatments. Treatments differ either in the tokens' type or supply (or both); see Table 3. Specifically, in some treatments, holding a token at the start of a round created a small gain or loss. Let u denote the flow payoff (in points) generated by holding a token at the start of a round. We say that the token is *plain* if $u = 0$ and *sophisticated*, otherwise. In the baseline setup (FIAT treatment) the tokens' type is *plain*, and there is a constant 4 unit supply. The main treatments PENALTY, REWARD, and REWARD2 consider *sophisticated* tokens granting small flow payoffs, $u = -1, 1, 2$ respectively.[5] We call u the *interest* paid by tokens.

Three additional treatments alter the supply of tokens. In FIAT2, the supply of plain tokens doubles to two per initial consumer. The MIX treatment alters the token supply composition by endowing initial consumers with one plain and one sophisticated token $u = 2$; this expands the action sets of Table 2 in the obvious way, adding one choice per player (use one token, or use the other). Finally, the SWITCH treatment is as in FIAT in the first two supergames, and plain tokens are replaced in later supergames by tokens that

[5]An alternative design where u is paid in tokens would generate an unstable token supply, unlike the baseline condition. An unstable token supply would add unnecessary complexity to the experiment—increasing the cognitive load in treated economies—and would also distort economic incentives for monetary trade relative to baseline economies.

pay 1 point per round on average (either 0 or 2 points based on a computer-generated coin flip). Because $-l < u < l$, total payoffs in a pair are positive in all treatments since $2d - l + u > 2(d - l) > 0$. Further details about the design and experimental procedures are in Appendix A.

Table 3: Treatments.

	Interest u		Token
Treatments	Token	Other Token	Supply
Main			
Fiat	0	—	4
Reward	1	—	4
Reward2	2	—	4
Penalty	-1	—	4
Additional			
Fiat2	0	0	4+4
Mix	0	2	4+4
Switch	0 then $\mathbb{E}[u]$ =1	—	4

4 A theoretical reference

Our setup captures two central features of the theory of money. First, there is an intertemporal reallocation of consumption that benefits everyone in the economy, which is difficult to accomplish because of trade frictions (typically, enforcement problems). Second, monetary exchange can emerge endogenously in response to these market frictions, but it is not imposed on participants because alternative non-monetary arrangements are also available. The experiment ensures that these alternatives compete on a theoretically-level playing field. In other words, a strategy exists, which supports the efficient allocation and does not require the use of tokens.

To demonstrate this, let *payoff* denote earnings expected ex-ante (start of supergame). Payoffs depend on the player's choices, those of future opponents, and the flow payoff u from tokens. The two main reference payoffs are associated with the *efficient* or *full cooperation* outcome, when producers never consume, and *autarky* or *full defection*, where only producers consume. Recalling the stage game payoffs definitions $g = 15, d = 6, l = 3, a = 0$, autarky payoffs to initial producers and consumers are

$$\hat{v}_p := \frac{d + \beta(d - l)}{1 - \beta^2} \qquad \text{and} \qquad \hat{v}_c := \frac{u + d - l + \beta(d + u)}{1 - \beta^2}.$$

Here, the tokens' flow payoff u affects only initial consumers, as tokens never change hands. It is immediate that autarky is a sequential equilibrium because D is always a best response to everyone playing D. But how can we support efficient play without tokens?

A non-monetary arrangement for efficient play. Suppose tokens are ignored. In the efficient outcome payoffs are

$$v_p := \frac{a + \beta g}{1 - \beta^2} \qquad \text{and} \qquad v_c := \frac{u + g + \beta(a + u)}{1 - \beta^2}.$$

Efficient play is supported as a sequential equilibrium by a simple trigger strategy: in equilibrium, a player chooses C as a producer, and switches to D forever after some producer choose D. Given public monitoring, if everyone adopts this strategy, then deviating to D triggers an immediate and permanent switch to autarky. Off-equilibrium, this sanction is incentive-compatible because playing D forever is an equilibrium, as seen above. Instead, defecting in equilibrium is suboptimal when $v_p \geq \hat{v}_p$, i.e., when the continuation probability

$\beta \geq \beta^* := \dfrac{d-a}{g-d+l}$. This holds in the experiment since $\beta^* = 0.5 < \beta = 0.75$.[6]

Proposition 1. *In all treatments, a non-monetary strategy exists that supports the efficient allocation as a sequential equilibrium.*

In non-monetary equilibrium, producers make *gifts* to consumers. Tokens never change hands in- or off-equilibrium, so their flow payoff u does not affect the existence conditions since initial producers never hold a token in or off-equilibrium. The condition $\beta \geq \beta^*$ is necessary and sufficient to support the efficient allocation as an equilibrium, but does not guarantee this outcome will emerge because in this indefinitely repeated game many other equilibria exist, including autarky. Tokens can also be used to support efficient play.

A monetary trading arrangement. Tokens assume the role of a currency and acquire value if cooperation is conditioned on their transfer. Let initial consumers have one token each. We say that a player adopts the *monetary trade strategy* if she chooses "spend" as a consumer and "sell" as a producer, whenever monetary trade is possible. In all other circumstances, a producer chooses D. If everyone adopts this strategy and no one deviates from it, then the economy is in monetary equilibrium. Here, monetary trade is possible in all pairs and all rounds because each consumer has 1 token, and each producer has 0. One token is exchanged quid-pro-quo for one good in every pair. This supports the efficient reallocation of goods, and also redistributes the flow payoff u across players—which has no social efficiency implications.[7] In monetary

[6]There are 16 rounds before randomization starts; $\beta \geq \beta^*$ ensures that cooperation is incentive-compatible in all rounds prior to randomization (see Bigoni et al., 2019).

[7]Off-equilibrium, some consumers may have no tokens, so not all meetings may allow monetary trade. Therefore, monetary trade alone cannot support 100% efficiency off equilibrium.

equilibrium the payoff to initial producer and consumer are

$$v_p(0) := \frac{a + \beta(u+g)}{1-\beta^2} \qquad \text{and} \qquad v_c(1) := \frac{u+g+\beta a}{1-\beta^2}.$$

A sufficient condition for the existence of monetary equilibrium is below.

Proposition 2. *If* $\beta \geq \beta^*(u) := \dfrac{d-a}{u+g-d+l}$, *then monetary trade is an equilibrium when each initial consumer is endowed with one token.*

The proof is in Appendix A. Existence of monetary equilibrium depends on a producer's incentive compatibility constraint: he must prefer delaying consumption, giving up a small benefit d for a larger benefit g next round. Hence, the threshold $\beta^*(u)$.

Intuitively, in monetary equilibrium there are two simultaneous transfers: one good goes from producer to consumer, and one token goes the opposite way. This outcome can also occur if the producer chooses C, but this is not part of the monetary strategy because it is dominated by Sell, which prevents the loss d in the event that a token is not received. For this reason, monetary trade is incentive-compatible off-equilibrium, also. Unlike the non-monetary trading norm, it relies on individual sanctions, instead of global, and temporary instead of long-lasting.

If $u = 0$, then payoffs in monetary and non-monetary equilibrium coincide, and the existence conditions are identical. Instead, if $u \neq 0$, monetary equilibrium redistributes part of tokens' flow payoffs to initial producers, altering the incentives to adopt monetary trade. If tokens carry a benefit $u > 0$, then deviating increases the economic loss for a producer (she gets no token) and, hence, the threshold discount factor supporting monetary equilibrium falls. The opposite holds true when tokens generate a penalty $u < 0$. It follows that the threshold $\beta^*(u)$ supporting the efficient allocation declines in u. In the experiment, $\beta^*(u) = 0.55, 0.50, 0.46, 0.43$ for, respectively $u = -1, 0, 1, 2$. This discussion immediately extends to the MIX treatment and, with some adjustment, to the FIAT2 treatment.[8]

Summing up, non-monetary and monetary strategies support 100% efficiency in all treatments. Cooperation is the result of *monetary trade* when consumer and producer both act in conformity with the monetary strategy (Spend and Sell in Table 2). It is the result of a *gift* when players follow the non-monetary strategy (Idle and C in Table 2). It should be clear that monetary trade and gifts are mutually exclusive cooperative outcomes, which generate the same amount of surplus. Cooperation can also result from a mix of these actions (Spend and C in Table 2), but this outcome is inconsistent with either equilibrium strategy.

The theory reveals that set of parameters supporting monetary equilibrium varies relative to non-monetary equilibrium, depending on the sign of u. This leads to two initial hypotheses.

H 1. *Monetary trade should be at least as frequent when tokens yield a benefit than when they do not.*

H 2. *Monetary trade should be no more frequent when tokens yield a penalty than when they do not.*

As noted earlier, existence of monetary equilibrium depends on a producer's incentive compatibility constraint. If there is an incentive to sell for a token, then there surely is an incentive to spend a token as consumers reap the

[8]In MIX, players can ignore one type of token and trade the other back and forth. In FIAT2, slightly adjust the monetary strategy to ensure that initial consumers are not tempted to spend their second token before producing for the first time. This temptation can be eliminated by specifying a reasonable set of beliefs off-equilibrium so that the condition supporting monetary equilibrium is the same as in Proposition 2; see Appendix B.

benefit g immediately.[9] Moreover, there is no economic incentive to produce for a token and hoard that token forever after because $d \geq \beta u/(1-\beta)$ for all $u \leq 2$. Hence, we put forward an additional hypothesis:

H 3. *Hoarding of tokens should not occur in any treatment.*

Combining sophisticated and plain tokens in Mix simply adds trading options. This neither removes the equilibria available in Fiat, nor prevents players from replicating Fiat trade patterns. This also holds true when sophisticated tokens that yield a benefit replace plain tokens in Switch. This leads to another hypothesis:

H 4. *Monetary trade should not decline when benefit-yielding tokens replace or complement plain tokens.*

5 Results

Theoretically, monetary and non-monetary equilibrium each support efficient play. Hence, it is helpful to give an overview by investigating the empirical relation between incidence monetary trade and economic performance in the experiment.[10] Let *profit* denote the points earned by a participant in the average stage game–excluding points earned from holding tokens. Depending on subjects' choices profit ranges from 1.5 to 10.5, is 7.5 points in the efficient outcome, and 4.5 points in autarky (see Appendix A.3). Realized surplus

[9]This is intuitive when $u \leq 0$, while for $u > 0$ if producers prefer to give up d for a token to be spent tomorrow to earn g, then consumers have an even greater economic incentive to trade because they give up $u < d - l$ tomorrow but earn g immediately.

[10]To enhance comparability across sessions, the analysis focuses on rounds 1-16 of a supergame. The average duration of a supergame was 19.6 rounds (min. 16, max. 32) with a standard deviation of 4.2. Rounds 1-16 capture 85% of all observations. Including periods beyond 16 increases noise in the data without affecting the nature of the results.

is the difference between *average* profit in the economy and autarky profits. Dividing this by its theoretical 3-points maximum gives *realized efficiency*; it is proportional to the average cooperation rate in the economy, ranging from 0% in autarky, to 100% under full cooperation.

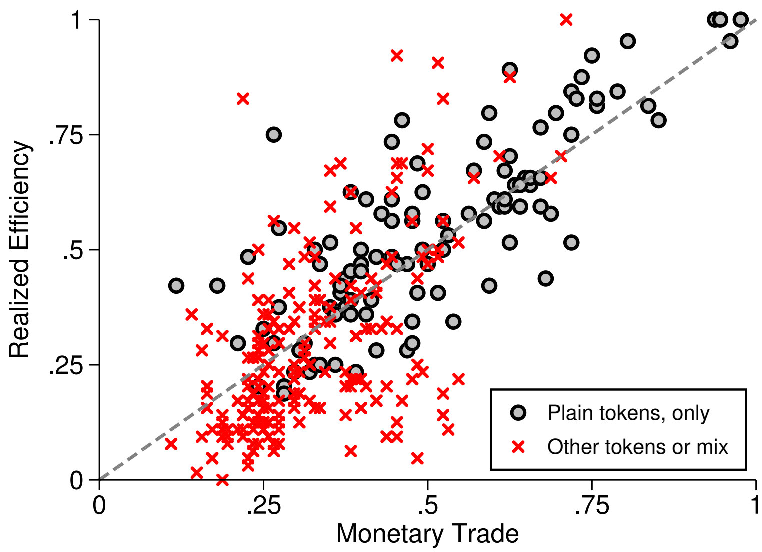
Result 1. *There is a positive association between realized efficiency and the frequency of monetary trade.*

Evidence is in Fig. 1 and Table B2. Fig. 1 reports realized efficiency against the frequency of strategy choices consistent with monetary trade, i.e., the frequency of choices "sell" and "spend." Each marker represents one economy. The frequency of monetary trade in the economy is directly tied to participants' choices in meetings where monetary trade is possible. It is also indirectly tied to the distribution of tokens that results from their choices, as this distribution pins down the share of meetings that can support monetary trade.[11]

The central observation is a strongly positive correlation between monetary trade and efficiency, 0.754. A GLM regression reveals that one standard deviation increment in the frequency of monetary trade is associated with an efficiency increment of about 19 percentage points. See the standardized *monetary trade* coefficient in Table B2 in Appendix B The positive association between efficiency and monetary trade is consistent with the finding that the use of money supports efficient play in groups of strangers (Camera and Casari, 2014; Camera et al., 2013). The novel observation is that realized efficiency and the exchange of tokens depend on the *type* of tokens made available to participants.

[11]Fig. 1 includes all meetings, including those where monetary trade was impossible as the consumer had no tokens (39% of all meetings, all treatments).

Figure 1: Monetary Strategy vs. Realized Efficiency: All Data



Notes: One obs.=one economy in a supergame (rounds 1-16), all data ($N = 315$). *Monetary Trade:* standardized average relative frequency of actions "sell" and "spend" in the economy.

Fig. 1 shows that economies endowed *only* with plain tokens (dots) tend to perform better than those endowed with sophisticated tokens (crosses). A majority of plain-tokens economies reached at least 50% realized efficiency as opposed to very few sophisticated-token economies (56% vs. 14%, N=61/108 vs. 30/207, respectively). In fact, this observation applies to any given efficiency level. [12] Monetary trade is also more frequent when tokens are plain. If monetary trade occurred whenever it was possible, then the markers in Fig. 1 should align along the 45 degree line. Markers above the 45 degree line indicate that efficient outcomes frequently occurred without tokens being exchanged. Markers are below the 45 degree if inefficient outcomes occurred when mone-

[12]The distribution of efficiency in economies endowed *only* with plain tokens stochastically dominates (in the first-order sense) the distribution in economies endowed with sophisticated tokens. See Fig. B1 in B.

tary trade was feasible—seen especially in sophisticated-tokens economies.

In a nutshell, not all tokens seem to be equally useful to support efficient play, in our experimental economies. The question is why. Did some token type slow the development of a monetary system, or altogether prevent it? If so, why did this happen? In what follows we offer an answer by studying how individual behavior and aggregate outcomes varied when we change the type of tokens from plain to sophisticated.

5.1 Plain tokens facilitate monetary trade

Participants in FIAT economies learned to coordinate on efficient play by increasingly relying on the exchange of tokens, as they gained experience with the task.

Result 2. *In FIAT economies monetary trade supported efficient play, and increased with experience.*

Evidence is in Fig. 2, Fig. B2 and Table B3. Fig. 2 reports the frequency of two mutually exclusive outcomes, monetary trade and gifts, in the average meeting. It reveals that cooperation was primarily supported by monetary trade, not by gift-giving.[13]

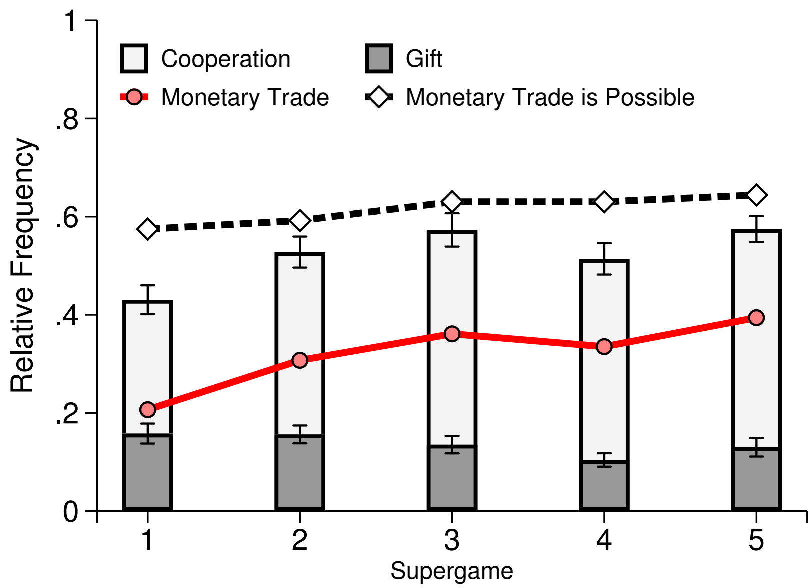
Monetary trade almost doubled from 0.21 to 0.39 over the course of the session, while the frequency of outcomes consistent with a gift being made hovered around 0.14.[14] In other words, average cooperation rose during the

[13] This is in line with the evidence reported in Camera and Casari (2014) and Camera et al. (2013). Monetary trade mitigates strategic uncertainty and facilitates coordination on efficient play; see Bigoni et al. (2020).

[14] This is not due to the presence of unconditional cooperators (only one player fits this profile) but to producers who sometimes made gifts when trade was impossible. An outcome is a gift when the producer neither demands nor receives a token as a result of her cooperation, i.e., cooperation is unconditional. Since tokens cannot be refused,

average session (from 0.43 in supergame 1 to 0.57 in supergame 5) because participants learned to exchange tokens for cooperation. Yet, we do not observe full cooperation.

Figure 2: Outcomes Experienced by a Participant in FIAT Economies



Notes: One obs.=one subject in a supergame, rounds 1-16 ($N = 72$ per supergame). *Cooperation:* relative frequency of cooperative outcomes. *Gift:* relative frequency of cooperative outcomes where no token is exchanged. *Monetary Trade:* relative frequency of cooperative outcomes where a token is exchanged. *Monetary Trade is Possible:* relative frequency of meetings where a token can be exchanged. The figure reports the average value across all subjects, while the whiskers identify the standard error of the mean.

The primary reason for the lack of full cooperation is that monetary trade was possible only in about 60% of meetings (dashed line in Fig. 2). The cause is heterogeneity in behavior, which pushed the token distribution off the theoretical monetary equilibrium. In particular, about 8% of players never attempted to cooperate as producers, and choose D unconditionally. As a result,

some unconditional cooperators received tokens in about 7% of meetings (the outcome corresponding to actions C and Spend in Table 2).

tokens did not optimally circulate and, hence, those interested in cooperation did not always have a token to spend as consumers.

The statistical significance of these empirical results is established by the panel regressions with random effects in Table B3 in Appendix B. Two observations stand out. First, the coefficient on the *Game* regressor is positive and highly significant in col. 3, and insignificant otherwise. That is to say, participants learned to coordinate on monetary trade but not on a non-monetary social norm of mutual support. Second, the coefficient on the *Trade Possible* regressor is highly significant in both columns, but while it is positive in the first, it is negative in the second. A one standard deviation increase in the frequency of trade meetings increased the frequency of cooperation by about 11 percentage points (col. 1), but decreased the frequency of gifts by about 7 percentage points (col. 2). Cooperation increased because individuals learned to rely on monetary trade, not on the unilateral transfer of gifts. An interpretation is that participants did not trust that a cooperative action would be later reciprocated by a stranger, unless a barren token was offered as compensation.

Cooperation did not reach 100% because acceptability problems did not get fully resolved by the end of the typical session. This kept pushing the token distribution off equilibrium, thus preventing the full development of a monetary trade convention. The constraining impact of this "illiquidity" on efficient play becomes apparent if we focus only on meetings where monetary trade was possible; see Fig. B2 in Appendix B. There, gift-giving outcomes were exceedingly rare, declining from 0.03 to 0. Cooperation significantly increased because monetary trade increased over time, reaching 0.58 by the end of the average session. Monetary trade did not reach 100% because some participants remained hesitant to demand tokens in exchange for cooperation. To explain, participants quickly learned that by offering tokens they could increase the chance of a cooperative outcome; the frequency of the Spend choice reached 0.94 by the end of the session. The Sell choice also became more frequent as the session progressed, but it remained below the Spend frequency. This acceptability problem is what constrained the growth in monetary trade and, hence, cooperation.[15]

The theory laid out in Section 4 suggests that if tokens could deliver a positive income flow ($u > 0$), then this would mitigate acceptability problems without causing hoarding issues. To investigate this hypothesis, we turn to study economies exclusively endowed with "sophisticated" tokens.

5.2 Sophisticated tokens hinder monetary trade

The treatments Penalty, Reward, and Reward2 replace plain tokens ($u = 0$) with sophisticated tokens ($u = -1, 1, 2$, respectively). Every else is identical to the Fiat treatment. Only the type of token changes.

Result 3. *Substituting plain with sophisticated tokens caused a decline in cooperation.*

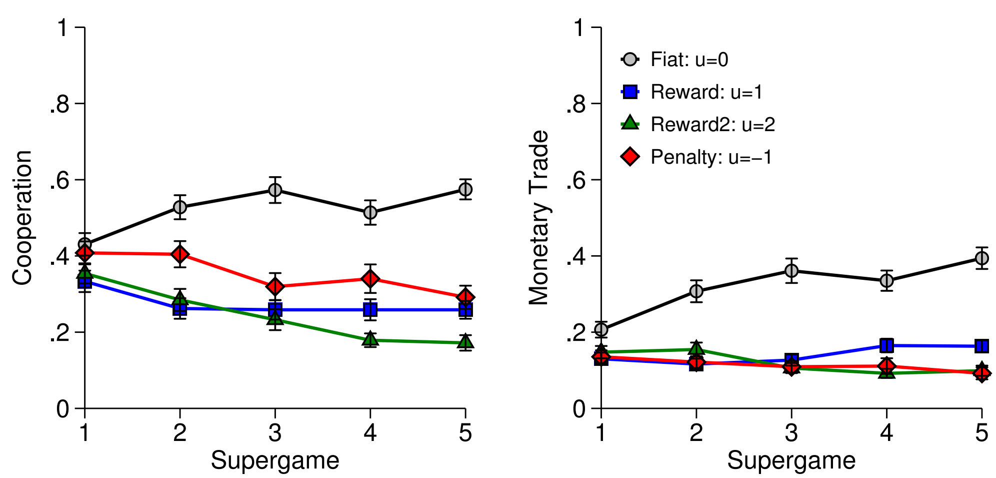
The left panel in Fig. 3 and column (1) in Table B5 provide evidence. The left panel in Fig. 3 shows the evolution of cooperation (equivalently, realized efficiency) during the average session, by treatment. Treatments are identified by the income flow u generated by one token at the start of a round. Note how average cooperation in the first supergame is similar across treatments, but this similarity quickly disappears as participants gained experience with the task. Overall, average cooperation in a session was 0.35, 0.27, and 0.24 in Penalty, Reward and Reward2, which are well below the 0.52 cooperation

[15] The statistical significance of these observations is confirmed by the panel regression in Table B4 in Appendix B.

rate recorded in Fiat. This decline in cooperation is statistically significant at the 10 percent level for $u > 0$, and insignificant for $u = -1$ (two-sided ranksum tests with exact statistics, $N = 3$ sessions per treatment).

Having few observations per treatment, the panel regression in Table B5 provides additional evidence. None of the treatment coefficients in col. 1 is statistically significant, suggesting that inexperienced subjects behaved similarly across treatments (this is confirmed by a regression that considers only data from supergame 1, not reported). Instead, in later supergames cooperation was lower in all treatments as compared to Fiat. All coefficients on *Treatment* $\times$ *Game* are negative and their sum with the *Game* coefficient is negative (Wald tests results are significant for Penalty and Reward2, p-values 0.005 and < 0.001, and insignificant for Reward).

Figure 3: Outcomes in Reward, Reward2, and Penalty.



Notes: One obs.=one subject in a supergame, rounds 1-16 ($N = 72$ per supergame, per treatment). The parameter $u = -1, 0, 1, 2$ identifies the treatment (see Table 3). *Cooperation:* relative frequency of cooperative outcomes. *Monetary Trade:* relative frequency of cooperative outcomes where a token is exchanged. For other details see Notes to Fig. 2. The Fiat treatment is added for comparison.

In summary, in the economies endowed with sophisticated tokens something interfered with participants' ability to learn to coordinate on efficient play. Not only cooperation did not improve when tokens generated positive income flows, but it progressively declined during the session. In other words, participants in economies endowed with sophisticated tokens learned to coordinate on *inefficient* play, which is opposite of what happened in plain-token economies. The cause of this failure is discussed next.

Result 4. *Endowing participants with sophisticated tokens, instead of plain, prevented the emergence of a monetary system.*

Evidence is in the right panel of Fig. 3 and cols. 2-3 in Table B5. The average frequency of monetary trade was 0.11, 0.14 and 0.12 for $u = -1, 1, 2$ economies, which are all significantly smaller than the 0.32 value recorded in FIAT (two-sided ranksum tests with exact statistics, p-value=0.10, $N = 3$). Monetary trade remained well below the levels observed in FIAT from the start of a session (this is statistically significant for $u = -1, 1$ according to a regression using supergame 1 data, not reported). Monetary trade also either did not improve or outright declined with experience. Evidence is in col. 3 of Table B5, where the *Treatment* coefficients are all negative (significant only for $u = 1$) and their interaction with the *Supergame* coefficient is also negative and significant. Hence, H1 can be rejected: benefit-yielding tokens did not facilitate monetary trade but, rather, prevented it. Instead, we cannot reject H2: when $u = -1$ tokens supported significantly less monetary trade as compared to the plain baseline $u = 0$.

Was this decline in trade the result of coordination on some non-monetary norm of cooperation? The data does not support this conjecture. The frequency of outcomes consistent with gifts being made did not differ from the

FIAT treatment: 0.13, 0.14, 0.11 and 0.10 for, respectively, $u = -1, 0, 1, 2$. Moreover, in sophisticated-token economies, gifts did not increase during the session. The significance of these observations is in col. 2 of Table B5: the coefficients on the *Treatment Indicators* and on their interaction with *Supergame* are all negative, and often significantly different from zero.

Summing up, endowing an economy with sophisticated tokens—instead of plain—precluded the spontaneous emergence of a monetary system. To uncover the possible reason(s) behind this outcome, we study individual choices in a meeting.

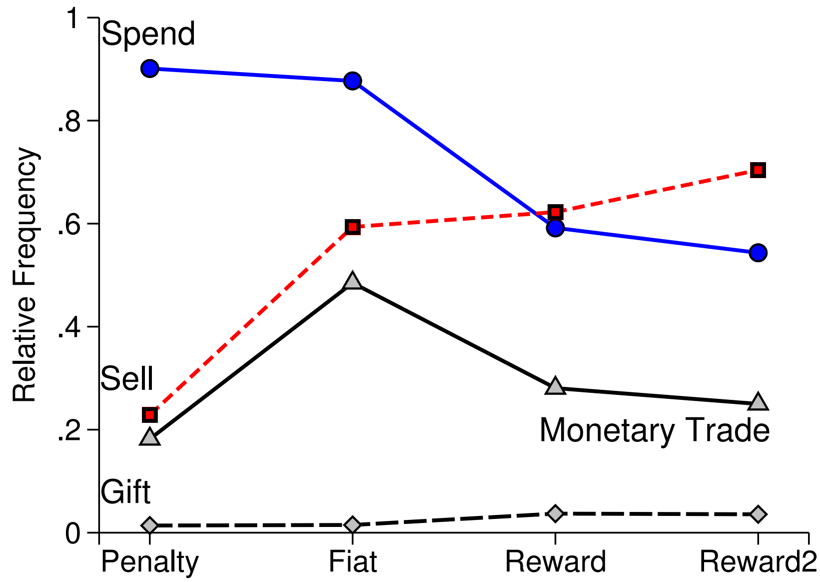
Result 5. *Adding a small penalty for holding tokens decreased tokens' acceptability. Adding a small benefit led to hoarding. Both interventions reduced tokens' circulation, as compared to plain tokens.*

Support is provided by Fig. 4 and Tables B6-B7 in Appendix B. Theoretically, the choice "spend" should be at least as frequent as the choice "sell" because in monetary equilibrium incentive compatibility constraints are slacker for consumers than producers (see Section 4).

Fig. 4 displays the average frequency of these two choices in meetings where monetary trade was possible. Adding a benefit from holding tokens improved their acceptability primarily for $u = 2$ (square markers); the frequency of the choice Sell is 0.59, 0.63 and 0.70 for $u = 0, 1, 2$ respectively. By contrast, tokens' acceptability dropped by half (0.29) when they carried a penalty $u = -1$.

To establish the significance of these observations we study the distribution of producers' choices in meetings where monetary trade is possible. Since producers have three actions available (D, C and Sell), and the dependent variable's categories have no natural ordering, a multinomial logit model is used where the Fiat treatment is the base of the regression. Marginal effects are reported in Table B6.

Figure 4: Outcomes & Choices when Monetary Trade was Possible



Notes: One obs.=one subject in a supergame, meetings where trade is possible in rounds 1-16 ($N = 72$ per supergame, per treatment). Mean frequency of actions Spend (circles) and Sell (squares), and of the mutually exclusive outcomes Monetary Trade (triangles) and Gift (diamonds). *Spend:* relative frequency of choice Spend as a consumer. *Sell:* relative frequency of choice Sell as a producer. *Monetary Trade:* relative frequency of cooperative outcomes where a token is exchanged. *Gift:* relative frequency of cooperative outcomes where no token is exchanged. The FIAT treatment is added for comparison.

Adding a one-point penalty from holding tokens significantly lowers acceptability by 0.35 points and increases the probability of defecting by 0.25 (see the *Penalty* coefficients in cols. 3 and 1). Adding a two-point reward causes the opposite shift: the probability of accepting tokens in exchange for cooperation increases by 16 percentage points, while the probability of defecting falls by 9 points. Adding a one-point reward induces a small and statistically insignificant increase in acceptance probability (in col. 3, the coefficients on *Reward2* and *Reward* are statistically different, Wald test, p-value=0.025).

The decline in tokens' acceptability induced by adding "holding costs" prevented a monetary system from developing in PENALTY economies. But what explains the lack of monetary trade when holding tokens yielded benefits? There, producers' demand for tokens *increased* relative to the plain-tokens setting, but consumers did not spend them, and hoarded them; see the circles in Fig. 4. The significance of these observations is established by a logit regression about consumer choices in meetings where trade was possible; the marginal effects are reported in regression (1), Table B7.

Consumers were significantly less likely to spend tokens when holding them entailed a benefit; the increment is of 40 and 49 percentage points, respectively for REWARD and REWARD2. Instead, introducing a one-point loss from holding tokens did not increase the probability to spend them relative to plain-token economies (see the *Penalty* coefficient). Based on this evidence H3 is rejected for treatments where $u = 1, 2$, but not for treatments where $u = -1, 0$ because in that case hoarding of tokens did not occur–consistent with theory.

Given these acceptability and hoarding problems, did players try to establish a cooperative norm based on the exchange of gifts? The answer is negative. The frequency of gifts did not increase as compared to FIAT, independent of whether monetary trade was possible or not in the meeting; see Fig. 4 and the treatment coefficients in regression (2) of Tables B6 and B7.

Summing up, endowing the economy with sophisticated instead of plain tokens, led to a significant decrease in cooperation and efficiency, because it stunted the development of a monetary trade convention. One may conjecture that this result could be reversed if participants were given the freedom to select between sophisticated or plain tokens, as a monetary instrument. This possibility is investigated in the remainder of this section.

5.3 Economies with competing tokens

Here we analyze the data collected from the MIX treatment, where each consumer had one plain token, *as well as* one token yielding 2 points from holding it. We compare it to the baseline FIAT treatment, with half the token supply, and also to the new FIAT2 treatment, where each initial consumer had two plain tokens. As explained in Section 4, these manipulations do not affect the existence of monetary and non-monetary equilibrium.

Result 6. *Efficiency and monetary trade declined in MIX as compared to both FIAT and FIAT2, where outcomes were instead similar.*

Fig. 5 and Table B8 (in Appendix B) provide evidence. Fig. 5 shows that cooperation in MIX economies started at levels similar to those seen in FIAT, and then steadily declined. The decline in cooperation occurred because participants did not learn to trade with tokens. Monetary trade (with any token) averaged 14%, which is well below that in FIAT. Moreover, the frequency of gifts declined from 0.15 to 0.06.[16]

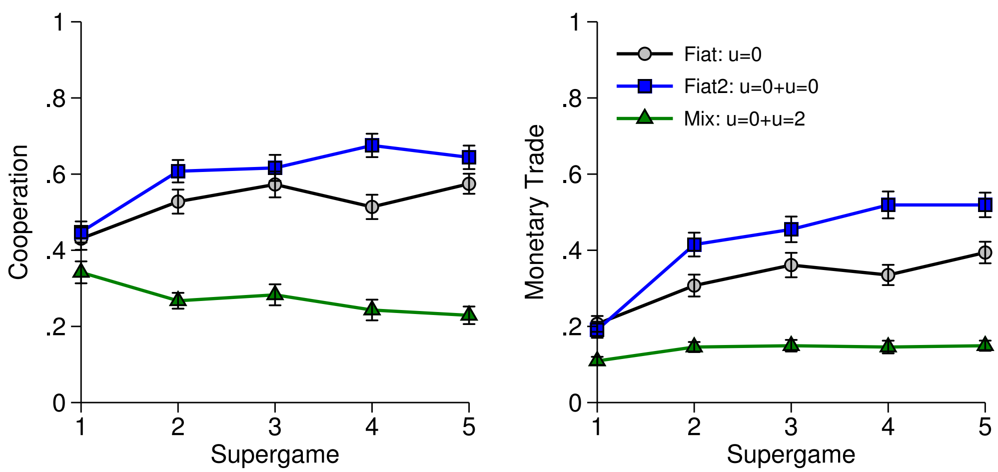
One may argue that FIAT is not the appropriate control for MIX because we have doubled the token supply. Doing so affects the frequency of meetings where monetary trade is possible and, therefore, might (adversely) affect the incentives to cooperate. Studying the FIAT2 treatment is thus helpful, because there we have as many tokens as in MIX but their composition is not heterogeneous—all tokens are plain.

If we use FIAT2 as the control, then the MIX manipulation appears to have

[16]These observations are significant according to the panel regressions in Table B8. The decline in cooperation is significant according to the sum of *Supergame* and *Mix* × *Supergame* coefficients in col. 1, which is negative and highly significant (Wald test). In col. 2 the *Mix* coefficient is negative and significant, the sum of *Supergame* and *Mix* × *Supergame* is statistically indistinguishable from zero (Wald test), while in col. 3 the sum of these two coefficients is negative and highly significant (Wald test).

a more dramatic effect. Monetary trade grew faster in FIAT2 economies as compared to FIAT. Intuitively, doubling the plain token supply made monetary trade possible in 83% of meetings as compared to 61% in FIAT. This boosted cooperation because, as seen before, cooperation increases when monetary trade is possible (see the coefficient on *Trade Possible* in col 1, in Table B8).

Figure 5: Outcomes in FIAT2 and MIX.



Notes: One obs.=one subject in a supergame, rounds 1-16 ($N = 72$ per supergame, per treatment). For definitions see the notes to Fig. 3. The FIAT treatment is added for comparison.

Fig. 5 shows that cooperation and monetary trade improved during FIAT2 sessions for the same reason they improved in FIAT: participants learned to coordinate on trading cooperation for a token, which in turn made trade possible in a greater share of meetings (this is significant according to a panel regression, not reported). Hence, Result 2 is robust to doubling the tokens' supply, but only if tokens are plain. In fact, monetary trade and cooperation increased significantly faster than in FIAT; in Table B8, columns 1 and 2, the sum of the coefficient on *Fiat2* and the interaction term *Fiat2* $\times$ *game* is positive and significant (Wald test).

The message from the Mix treatment is that Results 3-4 are robust to introducing a plain token in addition to an interest-bearing token. Economies where tokens yielded a small income flow attained lower efficiency levels than economies where tokens paid no interest. Hence H4 can be rejected for Mix. This result is surprising because Mix economies could have coordinated on using plain tokens as money, as we know subjects are capable of doing so in Fiat economies. Instead, giving participants a choice between a plain and a benefit-yielding token did not resolve the hoarding problems seen in Reward2, an in fact exacerbated the acceptability problems seen in Fiat.

Result 7. *In Mix, there was hoarding of sophisticated tokens, and lower acceptability of plain tokens relative to Fiat. Trading choices in Fiat2 did not differ from Fiat.*

Fig. B3 (in Appendix B) and Table 4 provide evidence by analyzing choices of producers and consumers in meetings where *some* token could be exchanged.

In Mix economies producers' demanded sophisticated tokens in exchange for cooperation much more frequently than plain tokens (respectively 61% vs. 18%). The opposite holds for consumers, who offered to spend plain tokens more frequently than sophisticated, respectively 73% vs. 42%; see Fig. B3. This incompatibility of trading choices precluded the emergence of a monetary trade convention because it created persistent miscoordination in meetings, resulting in many failed trades. As a result, offering plain tokens as a consumer, while refusing them as a producer prevented the circulation of either kind of token, plain or not. This precluded trade and, hence, cooperation and efficiency. By contrast, we do not see this happening in Fiat2 economies, because trading choices' frequencies were similar to FIAT economies (90% vs. 88% for Spend, and 59% vs. 53% for Sell); see Fig. B3. We thus can exclude that the effect on trading choices regarding plain tokens observed in MIX is due to the mere doubling of the token supply.

Table 4: Outcomes in a FIAT2 and MIX meeting: Marginal Effects.

Dep. variable= outcome	*D* (1)	*Failed Trade* (2)	*Gift* (3)	*Monetary Trade* (4)
Fiat2	0.008	-0.054	0.042	0.004
	(0.050)	(0.035)	(0.063)	(0.060)
Mix	0.017	0.343***	-0.063	-0.297***
	(0.043)	(0.069)	(0.069)	(0.037)

Notes: Multinomial logit regression on outcome experienced by producers in a meeting. One obs.=one producer in a period 1-16 of Fiat (the base of the regression), Fiat2, and Mix ($N = 6114$). Dep. Variables: *D* (the producer chose D), *Failed Trade* (the producer choose Sell for some token but the consumer's choice was incompatible), *Gift* (the producer chose C), and *Monetary Trade* (the producer choose Sell for some token and the consumer's made a compatible Spend choice). Robust standard errors (in parentheses) adjusted for clustering at session level. We also include a supergame regressor interacted with the treatment, a series of dummies for each period 1-16, and standard controls (not reported). Symbols $***$, $**$, and $*$ indicate significance at the 1%, 5% and 10% level, respectively.

A multinomial logit regression establishes the significance of these observations; marginal effects are reported in Table 4. In MIX players have two choices for monetary trade, while in FIAT and FIAT2 only one. Hence, the dependent variable is the outcome experienced by a producer in a meeting (not the producer's choice). This categorical variable can take one of four values: (i) "D" if the producer did not intend to cooperate (action D); (ii) "Failed Trade" if he intended to exchange cooperation for some token but the consumer made an incompatible choice (which leads to defection); (iii) "Gift" if he intended to make a gift (action C); and (iv) "Monetary Trade" if actions in the meeting led to the exchange of either token. Two indicator variables capture treatment effects (Fiat is the base of the regression), and the additional explanatory variables used in the earlier logit regressions are included.

We reject the hypothesis that doubling the supply of plain tokens significantly affected the distribution of outcomes (the coefficients on Fiat2 are all close to zero and insignificant). Instead, we cannot reject the hypothesis that supplying sophisticated tokens in addition to plain tokens—as done in Mix—affected outcomes. Doing so caused monetary trade to collapse by 30 percentage points due an increase in failed trades (the coefficient on *Mix* is negative and highly significant in cols. 2 and 4), a symptom of persistent incompatibility in consumers and producers' actions. In fact, there is no significant variation in the frequency of gifts or defection (the coefficient on *Mix* is small and insignificant in cols. 1 and 3).

Based on this analysis, we reject H3 for economies where players had access to both plain tokens and tokens that provided a benefit of 2 points. It seems that this freedom of choice acted as a coordination friction, preventing participants from developing a convention of monetary trade. A possible mechanism is the increased coordination complexity generated by giving players more choices—two types of tokens instead of just one. To assess this possibility, we ran the Switch treatment.

5.4 Engineering a transition to sophisticated tokens

The Switch treatment maintains the choice set and overall token supply of Fiat, while replacing plain with benefit-yielding tokens after the first two supergames. At the start of the session participants were informed that plain tokens would be replaced by other tokens in supergame 3, and would have been given the relevant details at the start of supergame 3.[17]

Recall that FIAT economies coordinated on monetary exchange rather quickly (see Fig. 2. Hence, if coordination complexity is responsible for the monetary trade decline in MIX, giving players a chance to initially coordinate on a monetary trade convention with plain tokens should facilitate a smooth transition to a monetary system supported by the exchange of benefit-yielding tokens. Furthermore, to mitigate the hoarding problems previously observed with benefit-yielding tokens, we lowered the attractiveness of the benefit. In SWITCH, a sophisticated token yields either 0 or 2 points with equal probability (iid across rounds).

The theory in Section 4 suggests that this treatment manipulation should not affect outcomes and, especially, the frequency of monetary trade should be similar to FIAT. Based on the data, we can reject this hypothesis.

Result 8. *In SWITCH, monetary trade and cooperation permanently declined after benefit-yielding tokens replaced plain tokens.*

Consider cooperation. In supergames 1-2, the levels in SWITCH and FIAT are similar (0.46 vs. 0.48), while they split apart in supergames 3-5 because cooperation falls in SWITCH while it grows in FIAT (0.35 vs. 0.55); see Figure B4 in Appendix B). This forking of efficiency levels hinges on the dynamics of monetary trade. In supergames 1-2, the frequency of monetary trade is slightly higher in SWITCH as compared to FIAT (0.31 vs. 0.26), while in supergames 3-5 monetary trade declines in SWITCH and grows in FIAT (0.27 vs. 0.36). In other words, in FIAT supergames 3-5 exhibit more cooperation than the

[17]The instructions informed subjects that in the first two supergames they had plain "white tickets," and subsequently they would be replaced by fancier "yellow tickets," with the finer details being provided at the start of supergame 3. See the Instructions in Appendix B. This was done both to simplify the cognitive load at the start of the session, and to facilitate the emergence of a monetary system early on.

first two because players learned to use tokens as a monetary instrument. By contrast, in Switch supergames 3-5 exhibit less cooperation than the initial two because players moved away from using tokens as a monetary instrument.

These observations are statistically significant according to a panel regression; estimates are reported in Table B9. The cause of this decline is the hoarding of benefit-yielding tokens. In supergames 3-5, consumers who had a token offered to spend it in 76% of meetings as compared to 92% of Fiat. Hence, we can reject H3-H4 for economies where tokens that yielded a small benefit replaced plain tokens. In other words, the coordination on efficient play observed in the initial plain-tokens economies did not fully spill over to sophisticated-tokens economies.[18]

6 Discussion

Central Bank digital currency, or CBDC, is poised to replace or complement traditional coins and banknotes in the near future. A crucial feature of the proposed new instruments is the possibility to generate small cash flows, positive or negative. In other words, this innovative digital currency can be interest-bearing. Standard theory does not raise specific concerns about this kind of innovation and, in fact, suggests that it could be beneficial for policy purposes. By interfacing standard theory with the experimental methodology, this study adds a much-needed empirical angle to this important debate.

The experiment provides evidence of a strong positive association between the frequency of monetary trade and realized efficiency (Result 1). When a monetary system did not emerge, or was poorly functioning, the frequency

[18]This difficulty in carrying over efficient play across similar indefinitely repeated games is also observed in (Duffy and Fehr, 2018), where coordination in a stag-hunt game does not bring about cooperation in a subsequent PD game, and vice-versa.

of efficient play collapsed as well. In other words, participants were largely incapable to coordinate on high-payoff equilibria without the support of a solid monetary system. This evidence confirms the findings about the nature of money earlier reported in Camera and Casari (2014), Camera et al. (2013) and Bigoni et al. (2020, 2019).

Why did transferring an intrinsically worthless token help to support cooperation? Coordinating on full cooperation in the experiment is not easy because players' incentives are imperfectly aligned. Trading a token for a cooperative action facilitates coordination on efficient play (Camera and Casari, 2014) as it mitigates the inherent strategic uncertainty problems (Bigoni et al., 2019). This coordination role of monetary exchange is extremely valuable when groups grow in size (Bigoni et al., 2019; Camera et al., 2013), and remains valuable also when reputational mechanisms are available (Bigoni et al., 2020). Two theoretical mechanisms can explain these findings. On the one hand, monetary trade makes cooperation evolutionarily stable because it boosts traders' fitness above that of free riders (Camera et al., 2013). On the other, monetary trade is risk dominant as it limits exposure to potential losses, while standard non-monetary norms of cooperation are not (Bigoni et al., 2019). Intuitively, trading tokens for cooperation offers three complementary advantages: (i) conditional cooperators can easily coordinate with like-minded individuals, even if there are few; (ii) it deters defections because those without tokens can only hope to earn income when meeting unconditional cooperators; (iii) it limits punishment to those without tokens, thus making cooperation more resilient to isolated misconduct.

In economies exclusively endowed with plain tokens, participants learned to optimally reallocate resources among themselves through monetary exchange (Result 2). By contrast, this outcome is not observed in economies exclusively endowed with sophisticated, interest-bearing tokens. These economies failed to develop a solid monetary system (Results 3-5). This is a novel result, which offers a fresh perspective for Central Bankers considering currency innovation. One may conjecture, perhaps naively, that penalizing currency holdings should discourage hoarding and boost spending, while rewarding holdings should make the instrument more attractive, encourage its acceptability, hence its circulation and value.[19] This is not what happened in the experiment. Introducing a negative interest on tokens degraded the monetary system because it sharply reduced acceptability without boosting spending, effectively making tokens a poor medium of exchange. Introducing a positive interest encouraged hoarding and failed to raise acceptability, thus reducing circulation. An insight is that penalizing currency holdings to boost spending might work as long as the demand for currency is sufficiently inelastic, while rewarding holdings to encourage acceptability might work if hoarding behavior is inelastic.

It is possible that this finding is not so much tied to payoffs of sophisticated tokens affecting behavior, but rather their greater complexity. If decisions are more complex when tokens bear an interest, then given bounded cognitive resources one expects worse decisions (e.g., Bossaerts and Murawski, 2017). Two considerations suggest this is not the primary channel in the experiment. On the one hand, the post-instructions quiz (see Appendix B) explained how to compute payoffs in all treatments, which mitigated possible treatment differentials in computational complexity for the problem confronting subjects. On the other, consider how outcomes in FIAT compare to those from the MONEY treatment in Bigoni et al. (2020, Table 3). Both have plain tokens, same subject pool, and fairly similar parameters. Yet, the tokens' complexity is greater

[19]For instance, Cœuré and Loh (2018) note that "The payment of (positive) interest would likely enhance the attractiveness of an instrument that also serves as a store of value."

in Money due to a larger choice set, which adds ten actions combinations to the six possible in Fiat. Comparing the data gives us an insight in the role that complexity might have played in our experiment because tokens' payoffs do not vary, only the decisional situation does. The differences in cooperation and monetary trade between the two conditions are insignificant, suggesting that greater tokens' complexity did not affect behavior (see discussion in Appendix B).

What explains the asymmetric responses of consumers and producers observed in the experiment? A possibility is a misalignment of incentives. With plain tokens, participants are theoretically indifferent between achieving efficient play through a monetary or non-monetary convention because the initial token distribution cannot affect the earnings distribution. By contrast, if tokens carry a positive interest, then initial producers (consumers) should prefer a monetary (non-monetary) convention, while the converse holds true if interest is negative. The difference in consumer and producer reactions observed in the experiment might thus reflect their desire to signal their preferred equilibrium. Another possible explanation is strategic uncertainty. If selection of the monetary equilibrium is uncertain, players might be tempted to take a safe action instead of risking a loss by trading; consumers might thus hoard tokens that yield benefits (as the token might not come back), while producers might refuse tokens that generate penalties (as the token might not be expendable).

These findings are robust. They emerge also when participants had a choice of instrument, plain or not (Results 6-7). This is surprising because a monetary system based on plain tokens was entirely feasible, theoretically and practically, as in a Gresham's Law equilibrium where the "bad" money circulates and the "good" money is hoarded. In fact, the simultaneous presence of a "good" and a "bad" token stunted the development of any kind of monetary system in the MIX treatment—sophisticated tokens were hoarded and plain tokens were seldom accepted. To explains this interesting finding, one might hypothesize that having more than one token type to choose from magnified coordination problems. Yet, the SWITCH treatment does not support this view; there, there was just one token type and yet monetary trade, which emerged when tokens were plain, unraveled when sophisticated tokens were introduced as a replacement (Result 8). In other words, the institution of money did not fully transfer *within* the sessions when sophisticated tokens replaced plain tokens. A second conjecture is that players failed to coordinate on a monetary convention in MIX due to conflicting incentives that led to a persistent incompatibility of choices: initial consumers insisted on offering plain tokens, while producers demanded sophisticated ones.

The angle of inquiry taken by this study can help evaluating the different typologies of currency innovation that lay ahead for Central Banks. A main insight form this experiment is that absent externally-imposed transaction catalysts, such as legal tender or full convertibility, the introduction of an innovative currency instrument may fail to achieve the desired result if it creates strategic uncertainty and mis-coordination. If players are unsure of what currency instrument others will use, this leads to monetary system instability. To the extent that the principles of operation in the experiment also apply to field economies, Central Banks can take preventive steps to manage the possible shortcomings of introducing a novel currency instrument. Legal tender laws could help mitigate acceptability problems, thought not eliminate them entirely; a regulatory framework that imposes clear limits on the size of possible benefits or penalties on the instrument might help reduce hoarding tendencies. Overall, this study is relevant in thinking about how to best design a new digital currency. It uncovers a desirable feature of a candidate currency instrument: it should be plain. Plain instruments might be ideal because they are unencumbered by the additional valuation margins inherent in more sophisticated instruments. In the experiment, these additional valuation aspects distorted decisions, preventing a focus on the instrument's fundamental role, which is to serve as a means of payment.

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