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

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Central banks are considering issuing new forms of digital money (CBDCs). A strategic analytical framework is used to investigate this currency innovation in the laboratory, contrasting a traditional "plain" tokens baseline to treatments where "sophisticated" tokens yield small payoffs. This theoretically beneficial innovation precluded the emergence of a stable monetary system, and lowered welfare. Similar problems emerged when sophisticated tokens complemented or replaced plain tokens. This evidence underscores the importance of combining theoretical with experimental investigation to guide currency innovation and the design of CBDCs.

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Central banks are considering issuing new forms of digital money (CBDCs). A strategic analytical framework is used to investigate this currency innovation in the laboratory, contrasting a traditional "plain" tokens baseline to treatments where "sophisticated" tokens yield small payoffs. This theoretically beneficial innovation precluded the emergence of a stable monetary system, and lowered welfare. Similar problems emerged when sophisticated tokens complemented or replaced plain tokens. This evidence underscores the importance of combining theoretical with experimental investigation to guide currency innovation and the design of CBDCs.

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1 Introduction

Many central banks are actively studying the conceptual and practical feasibility of issuing a new form of digital currency, or CBDC (Boar et al., 2020). This instrument can be quite sophisticated, incorporating features that go beyond making it just a digital version of sovereign physical coins and banknotes (Camera, 2017; Cœuré and Loh, 2018). Some envision this new instrument as yielding negative or positive cash flows, which is unlike traditional legal tender.[1] The possible ramifications of issuing a sophisticated currency and how to best design it have not been systematically studied and many questions are open. In particular: Would this 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" peer-to-peer instrument replaced or complemented a "plain" traditional instrument. The design leverages the strategic analytical framework developed in Camera and Casari (2014) as it captures general operating principles underlying monetary models, easily adapts to experimental investigation, and has a replicable baseline performance (Bigoni et al., 2020).

We create economies consisting of eight individuals who interact in random pairs where one person can produce a consumption good for the other. Incentives to produce exist because consumption benefits dominate production costs

[1] See for instance Ali et al. (2014); Broadbent (2016); Skingsley (2016), There is more than one reason behind this interest in currency innovation. Two often discussed reason are, first, a digital currency could raise payments systems' efficiency by reducing the costly layers of financial institutions that support the processing and settlement of electronic payments. A CBDC could also improve the speed and efficacy of intervention through the monetary transmission channel, especially if it could yield an interest. Some have argued that an interest-paying currency could improve business cycles stabilization and, if issued as a substitute for cash, could remove the current zero lower bound constraint on nominal interest rates; Bordo and Levin (2017) has a recent discussion.

and roles alternate for an indefinite number of periods. According to standard theory, these economies can support the intertemporal exchange of goods. Doing so is socially efficient, but Pareto-inferior equilibria also exist, with partial or even no production at all. To facilitate efficient play, we add a fixed supply of digital "plain" tokens with no intrinsic or redemption value, and no link to outside currencies. These can be used to support a monetary system where participants spontaneously trade production for a token. If so, plain tokens acquire value as payment instruments akin to traditional fiat currencies.

This baseline condition is contrasted to treatments where tokens are more "sophisticated" and can yield small payoffs, positive or negative (a CBDC). We study three different treatments with one type of token, two types of tokens, and a switch from plain to sophisticated tokens. By design, a strategy of monetary trade supports efficient play in all treatments, as well as a non-monetary strategy. Theoretically, the sophistication of tokens should not degrade economic performance and, in fact, tokens yielding small payoffs should be more attractive than plain tokens, 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 plain tokens stunted the spontaneous development of a monetary system, preventing coordination on efficient play and lowering average welfare. 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 findings form other experiments about fiat money (Bigoni et al., 2019). A novel result is that while participants in baseline economies learned to trade by exchanging plain tokens, this did not occur with sophisticated tokens. Giving tokens a small positive yield was sufficient to shift some individuals' focus away from maximizing the long-run payoffs made possible by alternating consumption to production, toward securing low but predictable gains by hoarding tokens. This myopic behavior created illiquidity, preventing the development of an effective monetary system. Instead, giving tokens a small negative yield sharply reduced tokens' acceptability and, hence, their value and use as payment instruments.

The insight is that traditional currency instruments outperformed more sophisticated ones because they were unencumbered by the additional valuation aspects associated with sophistication. These additional elements distorted decision-making and fostered myopic conduct that created frictions in the currency system. The study makes two kinds of contributions. From a substantive perspective, it demonstrates the importance of carefully designing a CBDC that is intended to offer a more efficient alternative to cash. Features that are seemingly desirable from a theoretical standpoint might have adverse practical consequences on the payment system. From a methodological perspective, the study brings to light the advantage of combining theoretical with experimental investigation to guide planning and decisions of monetary policymakers. In this manner, the study contributes to a growing body of knowledge showing how accounting for behavioral angles can improve overall policy assessment (Armantier and Holt, 2019; Duffy and Heinemann, 2020; Kryvtsov and Petersen, 2020).

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 co-authored studies that focus on 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 asynchronous exchange mediated by fiat or commodity-money and synchronous non-monetary trading systems (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 is support maximum welfare but unnecessary to attain it because alternative non-monetary strategies exist that support efficient play. The fol-

[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.

lowing 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 experimental design reflects this principle and makes explicit the trading process.

The model is an adaptation of the one in Camera and Casari (2014). The baseline 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). At the start of the economy every initial consumer is endowed with one plain "token," an indivisible electronic object that has no reference to outside currencies, cannot be redeemed for points or cash, and cannot be disposed of.

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 and both players can benefit from consuming it, respectively, $d = 6$ and $g = 15$ points for producer and consumer. The producer ultimately determines who consumes 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's payoff is g, and *defection* otherwise.

These outcomes can be the results of more than one combination of actions, as illustrated in Table 2. If the consumer has tokens, the producer can transfer the good to his counterpart (C, or "cooperate"), consume it (D, or "defect"), or offer to exchange it for one token (sell). Consumers can offer a token for the producer's good (spend) or take no action (idle). If the consumer has no tokens, only the producer makes a choice, D or C (shaded cells).

Players make simultaneous choices—so choices involving the exchange of tokens cannot signal intentions. Token exchange takes the form of a direct mechanism—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. Note that token holdings are unrestricted, so producers can always exchange their good for a token.[3]

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. In some treatments, a player was assigned or debited some points per token held at the start of the round – this payoff is not part of the table. 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, 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

[3]Limiting the consumer's action set to single-token offers simplifies subjects' cognitive task and fixes the price of tokens, removing speculative motives for token exchange. Subjects could see if the counterpart had some or no tokens, but not the exact holdings, to preclude identification and reputation-building. Producers could prevent token transfers by choosing D, which matters if losses can be incurred from holding tokens.

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 rounds as a supergame.

At the start of each round, players change roles and are randomly rematched with unform 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 economies. Hence, at each point in time three separate supergames are being played, starting and ending simultaneously. Each player in the session interacts in five economies. Once an economy ends, a new one is created so that no player can meet coun-

[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.

terparts from a previous economy. This minimizes dynamic spillover effects, and is disclosed to subjects.

Treatments. The payoff structure in Table 2 is common to all treatments, which differ only in the tokens' type, supply, or both; see Table 3. To define the token type, let u denote the flow payoff (in points) generated by holding a token at the start of a round. In the baseline setup (FIAT treatment) the tokens' type is *plain*, $u = 0$, and there is a 4 unit supply. The main treatments PENALTY, REWARD, and REWARD2 consider *sophisticated* tokens granting small flow payoffs, $u = -1, 1, 2$ respectively.

Table 3: Treatments.

	Flow payoff 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

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 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 experimental procedures are in Appendix A.

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 $\beta^* = 0.5 < \beta = 0.75$.[5]

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

[5]The experiment has a fixed number of rounds before randomization starts; $\beta \geq \beta^*$ ensures that cooperation is incentive-compatible in all periods prior to the start of randomization (see the Appendix in Bigoni et al. (2019)).

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.[6] In monetary 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. 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

[6]Off-equilibrium, some consumers may not have tokens in which case not all meetings can support monetary trade. Therefore, monetary trade alone cannot support 100% efficiency off equilibrium.

chooses C, but this is not part of the monetary strategy because it is dominated by "sell," which prevents the loss d if 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.

Payoffs in monetary and non-monetary equilibrium coincide when $u = 0$, 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 hods 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.[7]

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). Instead, it results from a *gift* when players follow the non-monetary strategy (The pos"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

[7] 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.

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 not decline when tokens yield a benefit instead of being plain.*

H 2. *Monetary trade should not increase when tokens yield a penalty instead of being plain.*

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. If there is an incentive to sell for a token, then there surely is an incentive to spend a token as consumers immediately reap the benefit g.[8] 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.*

[8]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.

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.[9] 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 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.*

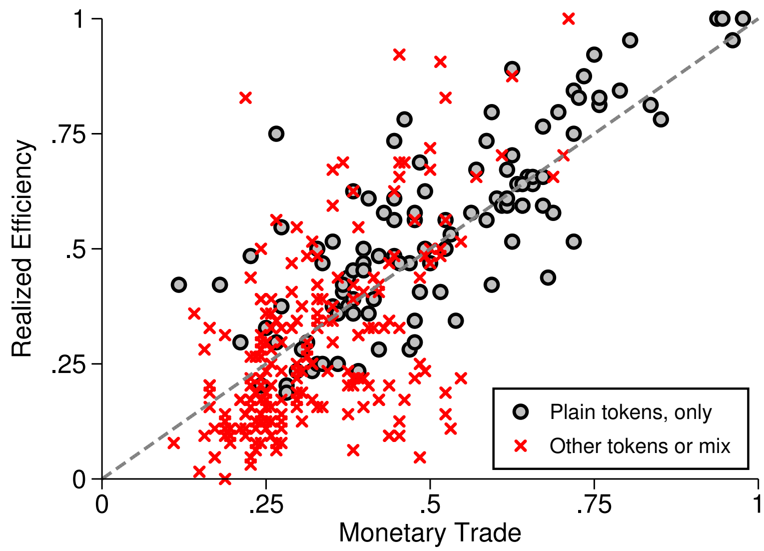
Evidence is in Fig. 1 and Table 4. Fig. 1 reports realized efficiency against the frequency of strategy choices consistent with monetary trade, i.e., the frequency of choices "sell" and "spend." Each marker represents one economy. The frequency of monetary trade in the economy is directly tied to participants' 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.[10]

[9] 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.

[10] Fig. 1 includes all meetings in the economy, including those where monetary trade was not possible because the consumer had no tokens, corresponding to 39% of all meetings (all treatments pooled together).

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 *monetary trade* coefficient in Table 4.

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



Notes: One obs.=one economy in a supergame (rounds 1-16), all data ($N = 45$ per treatment). *Monetary Trade:* average relative frequency of actions "sell" and "spend."

The unit of observation used in the regression is one economy, the dependent variable is realized efficiency. The regression includes treatment dummies, and a continuous *Supergame* regressor interacted with the treatment dummies to capture the impact of experience with the game. A set of additional standardized controls soaks up the effect of duration of the previous supergame, sex, and of the subjects' understanding of instructions according to two different measures from an incentivized quiz administered after reading the instructions (response time and wrong answers). Standard errors are adjusted for clustering at the session level.

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.

Table 4: Efficiency vs. Monetary Strategy Adoption.

Dep. var.: Realized Profit	Coeff.	S.E.
Monetary Trade	0.188***	(0.012)
Treatment dummies		
Penalty	0.005	(0.069)
Reward	-0.041	(0.075)
Reward2	-0.036	(0.069)
Fiat2	-0.077	(0.056)
Mix	-0.188***	(0.072)
Switch	-0.074	(0.051)
Other regressors		
Supergame	-0.017	(0.014)
Controls	Yes	
N	315	

Notes: GLM regression with robust standard errors (S.E.) adjusted for clustering at the session level. One obs.=one economy (rounds 1-16), all treatments. The regression includes interaction terms between treatments and the *Supergame* regressor. *Controls* include standardize measures of proportion of males in the economy, duration of previous supergame, and of understanding of instructions (response time and wrong answers in the quiz). Symbols $***$, $**$, and $*$ indicate significance at the 1%, 5% and 10% level, respectively.

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); this observation is robust to considering greater efficiency levels. The frequency of monetary trade also tends to be greater when tokens are not sophisticated. 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 monetary trade was feasible—something especially frequent 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 provide an answer by studying individual behavior and aggregate outcomes in economies endowed with various types of tokens.

5.1 Plain tokens facilitate monetary trade

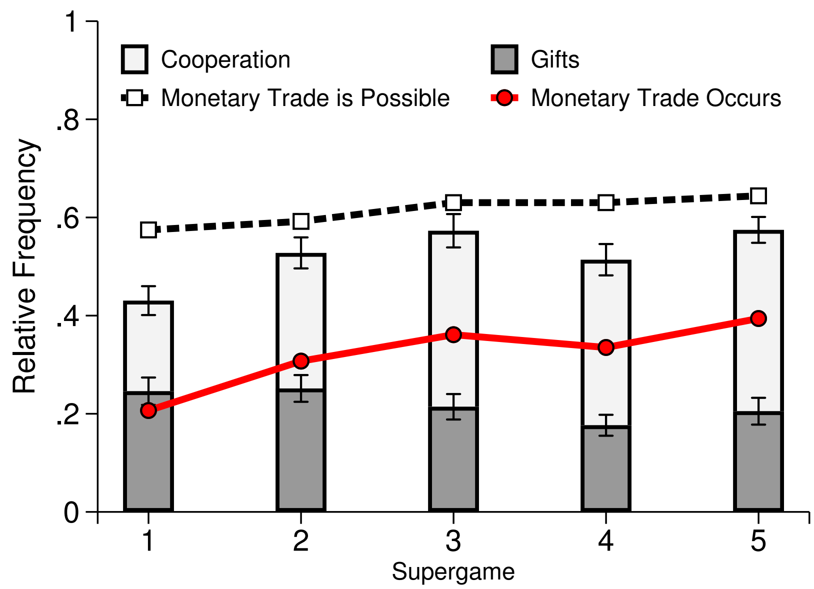
Participants in Fiat economies learned to coordinate on efficient play by increasingly relying on the exchange of tokens, as they gained experience with the task.

Result 2. *In Fiat economies monetary trade supported efficient play, which increased with experience.*

Evidence is in Fig. 2-3 and Table 5. Fig. 2 reports the frequency of two mutually exclusive outcomes, monetary trade and gifts, in the average meeting (independent of whether tokens could be exchanged in the meeting). It reveals that cooperation was supported by monetary trade, not by non-monetary norms of mutual help. Cooperative outcomes became more frequent s the session progressed, rising from 0.43 to 0.57. Instead, the frequency of gifts hovered around 0.20 while monetary trade almost doubled from 0.21 to 0.39 by the session's end.

Yet, efficiency did not exceed 60% in the data. This is largely due to monetary trade being impossible in about 40% of meetings (dashed line in Fig. 2) because the heterogeneity in behavior pushed the token distribution off equilibrium. About 8% of participants never attempted to cooperate and always choose D as producers. Others, did not always trade or make gifts. Cooperation was much higher in meetings where monetary trade was possible. Fig. 3 reveals that in these meetings participants learned to trade and not to make gifts. The exchange of tokens increased as participants gained experience with the task (from 0.33 in supergame 1 to 0.58 by the end of the session), while gifts account for only 3% of all outcomes.

Figure 2: Fiat Economies: all meetings



Notes: One obs.=one subject in a supergame, rounds 1-16 ($N = 72$ per supergame). The figure reports the mean, while the whiskers identify the standard error of the mean. *Cooperation:* relative frequency of cooperative outcomes. *Gifts:* relative frequency of outcomes in which cooperation occurred and no token was exchanged. *Monetary Trade is Possible:* relative frequency of meetings where monetary trade was possible; *Monetary Trade Occurs:* relative frequency of monetary exchange.

The statistical significance of these observations is established by the panel regressions with random effects in Table 5. The unit of observation is one individual in a supergame. The dependent variable is the average frequency of some outcome experienced by the player. Columns 1, 2 and 3, consider three different outcomes, respectively, cooperation, monetary trade, and a gift occurring in the meeting. We include a continuous *Trade Possible* standardized regressor to estimate how the possibility exchange a token affected outcomes, and the continuous *Game* regressor to determine how experience with the task affected behavior as the session unfolded. The set of additional controls discussed earlier is also included.

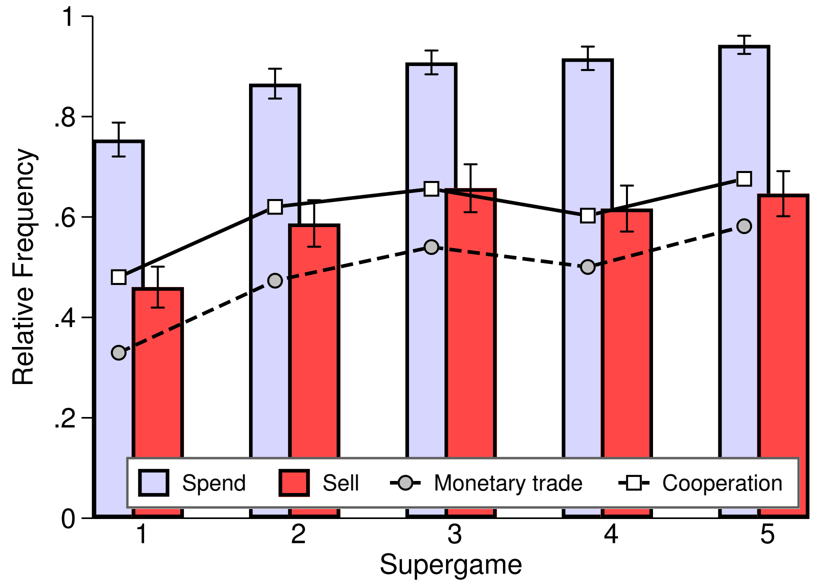
Table 5: Outcomes in FIAT Economies.

Dep. var.:	(1) Cooperation		(2) Monetary Trade		(3) Gift	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Trade Possible	0.112**	(0.045)	0.157***	(0.020)	-0.098***	(0.030)
Game	0.016	(0.015)	0.026***	(0.004)	-0.007	(0.014)
Controls	Yes		Yes		Yes	
Constant	0.468***	(0.084)	0.226***	(0.022)	0.244***	(0.080)
N	360		360		360	
R^2 within	0.232		0.525		0.269	
R^2 between	0.354		0.592		0.109	
R^2 overall	0.282		0.548		0.194	

Notes: Panel regression with random effects at the individual level and robust standard errors (S.E.) adjusted for clustering at the session level. One obs.=one subject in a supergame, rounds 1-16. For other details see notes to Table 4.

Two observations stand out. First, the coefficient on the *Game* regressor is positive and highly significant in col. 2, 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 all columns, positive in the first two and negative in the third. A one standard deviation increase in the frequency of trade meetings pushed monetary trade up by about 16 percentage points (col. 2), increased efficient play by about 11 percentage points (col. 1), and decreased the frequency of gifts by about 10 percentage points (col. 3). Cooperation increased because individuals learned to rely on monetary trade, not on a non-monetary norm of mutual support. It seems that participants did not trust that a cooperative action would be later reciprocated, unless a barren token was offered as compensation.

Figure 3: Fiat Economies: Meetings where Monetary Trade was Possible



Notes: One obs.=one subject in a supergame, rounds 1-16 when trade is possible only (N = 72 per supergame). The figure reports the mean of four measures of economic performance (the whiskers identify the standard error of the mean). *Spend:* relative frequency of choice "spend" as a consumer in the supergame. *Sell:* relative frequency of choice "sell" as a producer in the supergame. For the other measures see the notes to Fig. 2.

Fig. 3 reveals that monetary trade did not reach 100% due to acceptability problems. Subjects did frequently offer tokens in exchange for producers' cooperation; the frequency of the "spend" choice grew to 0.94 by the end of the session. However, this is not sufficient to establish a monetary system because participants must also be willing to accept tokens in exchange for cooperation as producers. Not every players did so; as a result, even if "sell" was chosen with increasing frequency as the session progressed, it remained below the "spend" frequency.[11] These acceptability problems limited the intensity of

[11] The statistical significance of these observations is confirmed by a panel regression (see Table A3 in Appendix B).

monetary trade.

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. Did this happen in the experiment? We investigate it in what follows, where we study economies in which participants had sophisticated tokens.

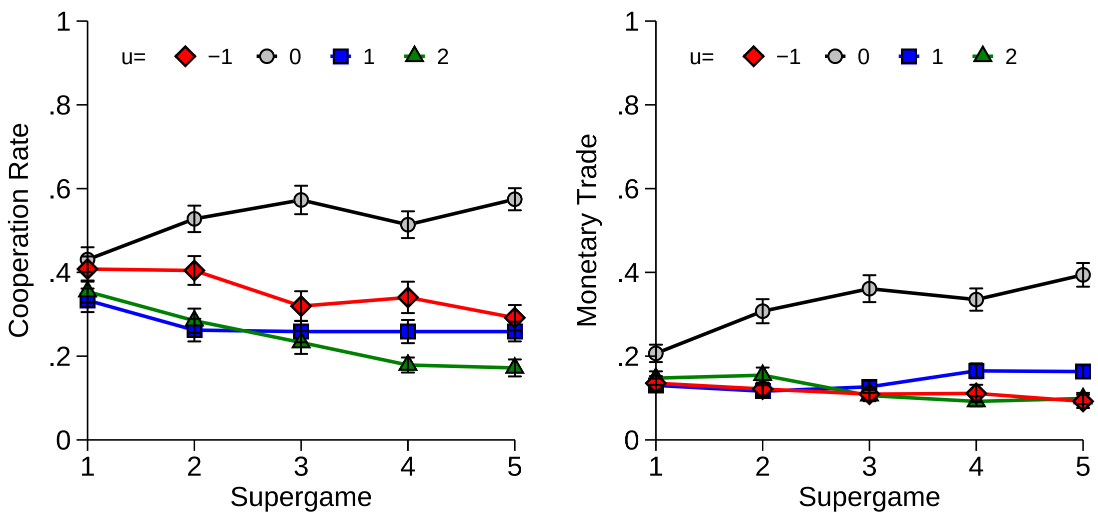
5.2 Sophisticated tokens hinder monetary trade

In the treatments Penalty, Reward, and Reward2 we altered the baseline treatment replacing plain tokens ($u = 0$) with sophisticated tokens characterized by, respectively, $u = -1, 1, 2$. The token supply remained fixed at four tokens per economy in all these treatments.

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

The left panel in Fig. 4 and column (1) in Table 6 provide evidence. The left panel in Fig. 4 shows the evolution of realized efficiency in sophisticated and plain token economies during the course of the average session. It reports average cooperation rates by supergame. Treatments are identified by the income flow u generated by one token. At the start of the session cooperation was similar in all treatments, but this similarity quickly disappeared as players gained experience with the task. Overall, the average cooperation rate in a session was 0.35, 0.27, and 0.24 in Penalty, Reward and Reward2, much lower than the 0.52 recorded in Fiat. In the economies endowed with sophisticated tokens something interfered with participants' ability to learn to coordinate on efficient play. In fact, not only cooperation did not improve but in some cases it progressively declined. In other words, the economies endowed with sophisticated often learned to coordinate on *inefficient* play, which is the opposite of economies endowed with plain tokens.

Figure 4: Outcomes in PENALTY, REWARD, REWARD2, and FIAT.



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). For other details see Notes to Fig. 2.

This decline is statistically significant at the 10 percent level when $u > 0$, and insignificant when $u = -1$ (two-sided ranksum tests with exact statistics, $N = 3$ sessions per treatment). The panel regression in Table 6 provides additional evidence.

Table 6: The Effect of Sophisticated Tokens on Outcomes.

Dep. var.:	(1) Cooperation		(2) Monetary Trade		(3) Gift	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Trade Possible	0.079***	(0.021)	0.087***	(0.015)	-0.063***	(0.012)
Treatment Indicators						
Penalty	0.001	(0.087)	-0.057**	(0.026)	0.015	(0.076)
Reward	-0.112	(0.080)	-0.084***	(0.027)	0.008	(0.084)
Reward2	-0.043	(0.084)	-0.022	(0.032)	0.000	(0.083)
Game	0.019	(0.014)	0.032***	(0.002)	-0.011	(0.012)
Penalty × Game	-0.048***	(0.018)	-0.040***	(0.007)	-0.014	(0.014)
Reward × Game	-0.032	(0.020)	-0.017*	(0.009)	-0.025*	(0.015)
Reward2 × Game	-0.061***	(0.013)	-0.042***	(0.005)	-0.025*	(0.014)
Controls	Yes		Yes		Yes	
Constant	0.424***	(0.070)	0.184***	(0.020)	0.265***	(0.076)
N	1440		1440		1440	
R^2 within	0.170		0.343		0.179	
R^2 between	0.401		0.559		0.042	
R^2 overall	0.299		0.457		0.115	

Notes: Panel regression with random effects at the individual level and robust standard errors (S.E.) adjusted for clustering at the session level. One obs.=one subject in a supergame 1-5, rounds 1-16 only. *Penalty*, *Reward* and *Reward2* take value 1 in the respective treatment and zero otherwise (*Fiat* serves as the basis of the regression). *Game* is a continuous regressor taking values 1-5, corresponding to the supergame in the session. *Controls* include duration of the previous supergame, self-reported sex, and two measures of understanding of instructions (response time and wrong answers in the quiz). Symbols $***$, $**$, and $*$ indicate significance at the 1%, 5% and 10% level, respectively.

The regression model is based on the one in Table 5, and now includes also three treatment indicator variables that are interacted with the supergame regressor (Fiat serves as the basis of the regression). 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* × *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).

In summary, participants did not coordinate on efficient play and, in fact, learned to play inefficiently when they had sophisticated instead of plain tokens. The cause of this failure is discussed next.

Result 4. *Substituting plain with sophisticated tokens prevented the emergence of a monetary system.*

Evidence is in the right panel of Fig. 4 and cols. 2-3 in Table 6. The average frequency of monetary trade was 0.11, 0.14 and 0.12 for $u = -1, 1, 2$ economies, less than half the 0.32 value recorded in FIAT. These differences are statistically significant at the 10 percent level (two-sided ranksum tests with exact statistics, $N = 3$). We also see that monetary trade was below the levels observed in FIAT from the start of a session (this statistically significant for $u = -1, 1$ but not $u = 2$ according to a regression for data of supergame 1, not reported) and either did not improve or outright declined with experience. In col. 2 of Table 6, the *Treatment* coefficients are all negative (though not significant for $u = 2$) and their interaction with the *Game* coefficient is also negative and significant. Hence, H1 can be rejected: benefit-yielding tokens did not facilitate monetary trade but rather prevented it. Instead, there is support for H2: tokens with $u = -1$ did not support monetary trade.

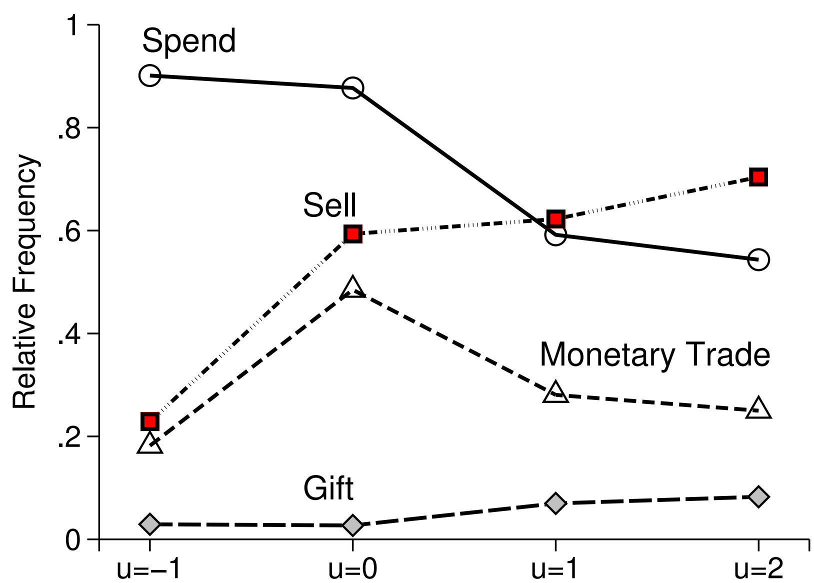
The absence of a monetary system was not the result of a preference for some non-monetary norm of cooperation. The overall frequency of gifts is similar across treatments, 0.21, 0.22, 0.18 and 0.17 for, respectively, $u = -1, 0, 1, 2$. In sophisticated-token economies, gifts declined over the course of the session; in col. 3 of Table 6 the coefficients on the *Treatment Indicators* are close to zero and insignificant, while the coefficient on their interaction with *Game* are negative (not always significant).

Summing up, endowing an economy with sophisticated tokens, instead of plain, prevented a monetary system from spontaneously emerging. To uncover the mechanism behind this outcome, we study choices at the individual level.

Result 5. *Introducing a penalty $u = -1$ for holding tokens decreased their acceptability relative to plain tokens. Introducing a benefit $u = 1, 2$ led to hoarding.*

Support is provided by Fig. 5 and Tables 7-8.

Figure 5: 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 outcomes Monetary Trade (triangle) and Gift (diamond). For definitions see the notes to Fig. 2-3.

Theoretically, the consumer's choice "spend" should be at least as frequent as the producer's choice "sell" because in monetary equilibrium incentive compatibility constraints are slacker for consumers than producers.

Fig. 5 displays the average frequency of the mutually exclusive outcomes monetary trade and gift, and of the choices "spend" and "sell" in all meetings where monetary trade was possible. Adding a small benefit to tokens improved their acceptability primarily when $u = 2$ (square markers); the frequency of the choice sell is 0.59, 0.63 and 0.70 for $u = 0, 1, 2$ respectively. By contrast, acceptability dropped by half (0.29) when tokens carried a penalty $u = -1$. The significance of these observations is established by a regression about the producer's choice in meetings where monetary trade is possible.

Table 7: Producer's choices: monetary trade is possible (marginal effects).

Dep. variable= choice	D	C	Sell
	(1)	(2)	(3)
Penalty ($u = -1$)	0.255*	0.099	-0.354***
	(0.135)	(0.095)	(0.063)
Reward ($u = 1$)	0.014	-0.061	0.047
	(0.048)	(0.040)	(0.053)
Reward2 ($u = 2$)	-0.091**	-0.065	0.156**
	(0.041)	(0.040)	(0.064)
N	6265	6265	6265

Notes: Multinomial logit regression on producer's choices D, C, or Sell, when monetary trade is possible. One obs.=one subject in a period 1-16 of Fiat (the base of the regression), Reward1, Reward2, and Penalty. Robust standard errors (in parentheses) adjusted for clustering at session level. The regression includes 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.

Since producers have three actions available, and the dependent variable's categories have no natural ordering, a multinomial logit model is used; marginal effects are in Table 7. The Fiat treatment is the base of the regression. In col. 3, the *Penalty* coefficient is negative and highly significant; it is otherwise positive but significant only for *Reward2* (and statistically different from the coefficient on *Reward*, Wald test, p-value=0.025).

The decline in acceptability is the friction that prevented a monetary system from developing in PENALTY economies. But what explains the lack of monetary trade when tokens yielded benefits? There, acceptability *increased* relative to our baseline plain-tokens setting, but consumers hoarded tokens; see the circles in Fig. 5. Table 8 reports the marginal effects of a logit regression about consumer choices in meetings where trade was possible.

Table 8: Hoarding and Gifts (marginal effects).

Dep. var.:	(1) Consumer chooses "spend" (monetary trade possible)		(2) Producer chooses C (monetary trade impossible)	
	Coeff.	S.E.	Coeff.	S.E.
Penalty	0.026	(0.029)	-0.064	(0.097)
Reward	-0.401***	(0.058)	-0.163	(0.126)
Reward2	-0.490***	(0.082)	-0.174*	(0.094)
N	6265		5255	

Notes: Logit regression on consumer's choices when trade is possible, and producer's choices when trade is impossible. One obs.=one subject in a period 1-16 of FIAT (the base of the regression), REWARD1, REWARD2, and PENALTY. Robust standard errors (in parentheses) adjusted for clustering at session level. Columns 1-2: dependent variable is one when the consumer chooses to offer a token, 0 otherwise. Columns 1-2: dependent variable is one when the producer chooses to make a gift, 0 otherwise. The FIAT treatment is the base of the regression. 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.

Col. 1 reveals that consumers were significantly less likely to spend a token when holding it entailed a small benefit (see the *Reward* and *Reward2* coefficients), while introducing a small penalty did not significantly increase the spend frequency relative to plain tokens (the *Penalty* coefficient is insignificant). 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.

Did monetary trade fail just because economies endowed with sophisticated tokens supported efficient play by non-monetary means? The answer is negative. As compared to FIAT, the frequency of gifts did not increase in any meeting, independent of whether monetary trade was possible or not; see col. 2 of Tables 7 and 8 (the positive treatment coefficient in Table 7 is small and insignificant).

Summing up, endowing participants with sophisticated tokens, instead of plain, caused a collapse in monetary trade and in realized efficiency. One may conjecture that this result would be reversed if participants were free to select between sophisticated or plain tokens as a monetary instrument. We consider this possibility in what follows.

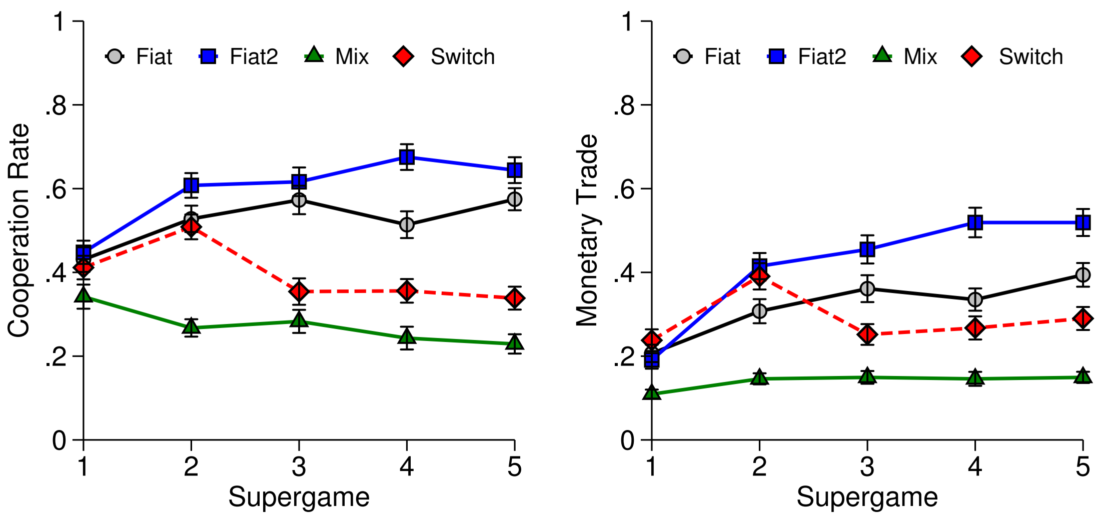
5.3 Economies with competing tokens

Here we analyze the data collected from the FIAT2 and MIX treatments. In FIAT2, each initial consumer had two plain tokens; in MIX, they also had two tokens but one was plain and the other sophisticated, yielding $u = 2$. As explained in Section 4, these manipulations are inconsequential for the existence of monetary and non-monetary equilibrium.

Result 6. *Outcomes in FIAT2 and FIAT were similar. Instead, efficiency and monetary trade declined in MIX as compared to both FIAT2 and FIAT.*

Fig. 6-7 and Table 9 provide evidence. Fig. 6 illustrates the close similarity in cooperation rates between FIAT2 and FIAT. In both treatments cooperation and monetary trade improved over the course of the session. The panel regression in Table 9 mirrors the econometric model in Table 6. In col. 1, the coefficient on *Fiat2* is small and insignificant, and so is the coefficient on the interaction term *Fiat2* $\times$ *game*. Hence, Result 2 is robust to doubling the supply of plain tokens.

Figure 6: Outcomes in FIAT2, MIX, SWITCH and FIAT.



Notes: One obs.=one subject in a supergame, rounds 1-16 ($N = 72$ per supergame, per treatment). *Cooperation:* average relative frequency of cooperation in a supergame. *Monetary Trade:* average relative frequency of monetary trade occurring in a supergame. The whiskers identify the standard error of the mean.

It is important to observe that in FIAT2 the feasibility of a monetary trade increased relative to FIAT because the supply of tokens was doubled. Trade was possible with frequencies 0.83 in FIAT2 as compared to 0.61 in FIAT. As a result, monetary trade increased more during FIAT2 sessions than in FIAT. This observation explains the positive and significant interaction term coefficient in col. 2 of Table 9.[12] Finally, as seen earlier, gifts declined as the

[12]It also explains why we have a negative and significant coefficient on *Fiat2* in col. 3; all else equal, doubling the token supply lowered the frequency of monetary trade since now monetary trade meetings in which both producer and consumer have a token are more likely, and trade should not occur in these meetings.

frequency of monetary meetings increased; see the negative coefficient on the *Trade Possible* coefficient in col. 3.

Table 9: The effect of adding tokens.

Dep. var.:	(1) Cooperation		(2) Monetary Trade		(3) Gift	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Trade Possible	0.096***	(0.023)	0.130***	(0.019)	-0.085***	(0.015)
Treatment Indicators						
Fiat2	-0.051	(0.083)	-0.107**	(0.046)	0.045	(0.066)
Mix	-0.142	(0.106)	-0.154***	(0.033)	0.016	(0.094)
Game	0.019	(0.014)	0.028***	(0.003)	-0.007	(0.012)
Fiat2 × Game	0.010	(0.016)	0.025***	(0.005)	-0.017	(0.013)
Mix × Game	-0.045***	(0.015)	-0.022***	(0.008)	-0.022*	(0.012)
Controls	Yes		Yes		Yes	
Constant	0.498***	(0.064)	0.284***	(0.024)	0.198***	(0.067)
N	1080		1080		1080	
R^2 within	0.197		0.418		0.292	
R^2 between	0.528		0.652		0.171	
R^2 overall	0.390		0.536		0.237	

Notes: Panel regression with random effects at the individual level and robust standard errors (S.E.) adjusted for clustering at the session level. One obs.=one subject in a supergame 1-5, rounds 1-16 only. *Fiat2*, and *Mix* take value 1 in the respective treatment and zero otherwise (*Fiat* serves as the basis of the regression). *Game* is a continuous regressor taking values 1-5, corresponding to the supergame in the session. *Controls* include duration of the previous supergame, self-reported sex, and two measures of understanding of instructions (response time and wrong answers in the quiz). Symbols $***$, $**$, and $*$ indicate significance at the 1%, 5% and 10% level, respectively.

Now compare the outcomes in Fiat2 with those in Mix where we also doubled the overall token supply by giving each initial consumer one sophisticated and one plain token.

The main message of Fig. 6 and Table 9 is that Results 3-4 are robust to introducing two competing tokens in Mix. Fig. 6 shows that cooperation was initially close to Fiat but significantly declined over the course of the session. This decline is statistically significant; the sum of *game* and *Mix* × *game* in col. 1 is negative and highly significant. On the other hand monetary trade started and remained below the FIAT levels for the entire session (the average is 0.14), while the overall frequency of gifts declined (from 0.22 to 0.10).[13] In fact, since altering the token supply affects the frequency of meetings where monetary trade is possible, FIAT2 is the appropriate control treatment for MIX. If so, the negative effect cause by adding sophisticated tokens and plain tokens is even more dramatic, since monetary trade in FIAT2 economies was even higher than in FIAT.

Hence H4 can be rejected for MIX. This result is surprising because participants could have coordinated on using plain tokens as money—we know they are capable of doing so from FIAT data. Instead, giving participants a choice of token simply exacerbated the acceptability problems seen in FIAT, without resolving the hoarding problems seen in REWARD2. This acceptability decline was not observed in FIAT2, so it is not due to the doubling of the token supply.

Result 7. *Participants' choices in FIAT2 did not differ from FIAT. In MIX, the acceptability of plain tokens declined relative to FIAT, and participants hoarded sophisticated tokens.*

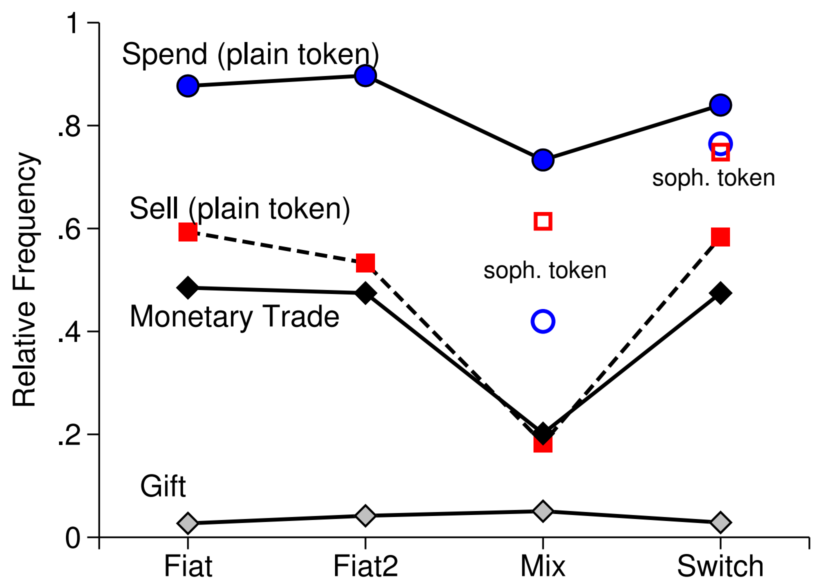
Fig. 7 and Table 10 provide evidence by analyzing choices of producers and consumers in meetings where *some* token could be exchanged.

Participants' choices in FIAT2 and FIAT economies are similar; see the corresponding markers in Fig. 7. Instead, MIX economies reveal that producers accepted sophisticated tokens (empty square) and seldom plain tokens (filled square), while consumers offered plain tokens (filled circle) and hoarded sophisticated tokens (empty circle). This choice incompatibility precluded

[13]In col. 2 the *Mix* coefficient is negative and significant, while the sum of *game* and *Mix* $\times$ *game* is statistically indistinguishable from zero (Wald test). Col. 3 indicates that gifts also declined (the sum of *(Super)game* and *Mix* $\times$ *game* is negative and significant, p-value$<$ 0.001, Wald test).

the emergence of a monetary convention because it created persistent mis-coordination of actions. This prevented circulation of sophisticated tokens, simultaneously making plain tokens illiquid.

Figure 7: Outcomes & Choices when Trade was Possible: Other Treatments



Notes: One obs.=one subject in a supergame, meetings where trade is possible in rounds 1-16 ($N = 72$ per supergame, per treatment). The figure reports the mean of four measures of economic performance (for definitions see the notes to Fig. 2-3). In the Mix and Switch treatments, a filled marker refers to the choice about plain tokens ($u = 0$), while an empty marker denotes choices about sophisticated tokens ($u = 2$ in Mix, and $u = 0, 2$ with equal probability in Switch).

A multinomial logit regression is used to assess the significance of these observations; marginal effects are reported in Table 10. 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 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) "C" if he made a gift (action C); and (iv) "Monetary Trade" if both actions in the meeting supported monetary trade based on 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.

Table 10: Outcomes in a meeting–Marginal Effects (FIAT2 and MIX)

Dep. variable= outcome	*D* (1)	*Failed Trade* (2)	*C* (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)
N	6114	6114	6114	6114

Notes: Multinomial logit regression on outcome experienced by producers in a meeting: *D* (the producer chose D), *Failed Trade* (the producer choose "sell" for some token but the consumer's choice was incompatible), *C* (the producer chose C), and *Monetary Trade*. One obs.=one producer in a period 1-16 of Fiat (the base of the regression), Fiat2, and Mix. 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.

We reject the hypothesis that doubling the supply of plain tokens affected 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 affected outcomes. Doing so did not significantly affect the frequency of gifts or defection (the coefficient on *Mix* is small and insignificant in cols. 1 and 3), but 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 disagreement in consumer and producer actions.

Based on this we reject H3 for economies where players had access to plain and sophisticated tokens. 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. 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 as in FIAT. It simply replaces plain with sophisticated tokens one-for-one at the start of the third supergame. Recall that FIAT economies coordinated on monetary exchange relatively quickly. If coordination complexity is responsible for the monetary trade decline in MIX, then switching tokens after two supergames should be enough to support a seamless token switch that does not impair the monetary trade convention. To mitigate the hoarding problems previously observed, sophisticated tokens yielded either 0 or 2 points with equal probability (iid across rounds). Furthermore, to minimize confusion, participants were informed that plain tokens would be replaced by other tokens starting in supergame 3, with the exact details being provided at the start of supergame 3.[14]

Our hypothesis is that this manipulation should not affect outcomes and the frequency of monetary trade in any supergame, as compared to FIAT.

[14] Instructions informed subjects that in the first two supergames they had plain "white tickets," while afterward they would switch to fancier 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.

In fact, while this manipulation neither affected realized efficiency or the frequency of monetary trade in supergames 1-2, it did significantly affect outcomes and choices in supergames 3-5.

Result 8. *In* S*WITCH, monetary trade and cooperation permanently declined after sophisticated tokens replaced plain tokens.*

Fig. 6-7 and Table 11 provide evidence. Outcomes in SWITCH and FIAT are similar in supergames 1-2 but not in later supergames, when cooperation and monetary trade dropped as compared to FIAT; see Fig. 6. These observations are statistically significant according to the panel regression in Table 11.

Table 11: Outcomes in Economies with a Switch of Tokens.

Dep. var.:	(1) Cooperation		(2) Monetary Trade	
	Coeff.	S.E.	Coeff.	S.E.
Trade Possible	0.119***	(0.021)	0.160***	(0.011)
Switch	-0.031	(0.048)	0.041**	(0.017)
Games 3-5	0.039*	(0.022)	0.063***	(0.008)
Switch × Games 3-5	-0.112***	(0.027)	-0.056***	(0.018)
Controls	Yes		Yes	
Constant	0.481***	(0.055)	0.257***	(0.015)
N	720		720	
R^2 within	0.280		0.488	
R^2 between	0.397		0.564	
R^2 overall	0.329		0.510	

Notes: Panel regression with random effects at the individual level and robust standard errors (S.E.) adjusted for clustering at the session level. One obs.=one subject in a supergame 1-5, rounds 1-16. *Switch*=1 in that treatment, 0 otherwise (*Fiat* is the base of the regression). *Games 3-5*=1 in supergames 3-5 (0, otherwise). *Controls* include duration of the previous supergame, self-reported sex, and two measures of understanding of instructions (response time and wrong answers in the quiz). Symbols $***$, $**$, and $*$ indicate significance at the 1%, 5% and 10% level, respectively.

In each column the coefficient on the *Switch* indicator is close to zero and insignificant, suggesting no treatment effect when tokens were plain (supergames 1-2). By contrast, moving away from plain tokens caused a decline in cooperation and monetary trade relative to FIAT treatment; the coefficient on *Switch* $\times$ *Games 3-5* is negative an highly significant, while it is positive and significant on *Games 3-5*. The same holds true for the frequency of monetary trade (see col. 2).

The cause of this decline is illustrated in Fig. 7, where we report the frequency of actions in meetings where monetary trade was possible. In SWITCH, producers more readily accepted sophisticated than plain tokens, but consumers were also less willing to spend them. Hence, we can reject H3-H4 for economies where tokens that yielded a small benefit replaced plain tokens.

6 Discussion

Peer-to-peer sovereign digital tokens, or CBDCs, seem poised to replace or perhaps complement coins and banknotes in the near future. An interesting aspect of these digital instruments is the possibility to generate small cash flows, positive or negative. Standard theory does not raise specific concerns about introducing features of this kind in a currency instrument and, in fact, suggests that it could be beneficial for policy purposes. By interfacing standard theory with the experimental methodology, this experiment 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 of efficient play collapsed as well. In other words, participants were largely incapable or unwilling to replace a poorly-functioning monetary system with a social norm of cooperation despite the possibility to monitor collective behavior. This evidence confirms previous findings about the nature of money, reinforcing the view that money is more than just a crude substitute for monitoring past play (Bigoni et al., 2019).

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 when we exclusively endowed participants with "better" tokens, which yielded small payoffs. These economies failed to developed a solid monetary system (Results 3-5). This is a novel result, which offers a fresh perspective for policymakers planning currency innovation. Roughly speaking, one may conjecture that penalizing currency holdings should discourage hoarding and boost spending, while rewarding them should make the instrument more attractive, encourage its acceptability, and consequently its circulation and value.[15] This is not what happened in the experiment. Introducing a negative yield 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 yield encouraged hoarding while failing 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.

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 a non-monetary convention because the dis-

[15]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."

tribution of tokens cannot affect the distribution of earnings. By contrast, if tokens have a positive yield, then producers prefer a monetary to a non-monetary convention, while the converse holds true if the yield is negative. Preferences of initial consumers are just the mirror-image. The opposite reaction of consumers and producers observed in the experiment can thus reflect participants' 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 risk a loss by trading; consumers will hoard tokens that yield benefits (as the token might not come back), while producers will 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, in the experiment the simultaneous presence of a "good" and a "bad" money stunted the development of any kind of monetary system—sophisticated tokens were hoarded but plain tokens were seldom accepted. What explains this unique finding? One might imagine that having more than one token choice crated insurmountable coordination problems. Yet, the SWITCH treatment does not support this view; there, there was just one type of token and yet monetary trade initially emerged but unraveled when sophisticated tokens replaced plain ones (Result 8). In other words, the institution of money did not fully transfer *within* the session 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. 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 a novel currency design as observed in the experiment. Legal tender laws could help mitigate acceptability problems, thought not eliminate them entirely, while 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 are ideal because they are unencumbered by the additional valuation margins inherent in more sophisticated instruments. In the experiment, these additional valuation considerations distorted decisions, preventing a focus on the instrument's fundamental role, which is to serve as a means of payment.

References

Abreu, D., D. Pierce and E. Stacchetti . 1990. Toward a Theory of Discounted Repeated Games with Imperfect Monitoring. *Econometrica*, 58, 1041-1063.

Ali, R, J. Barrdear, R. Clews and J. Southgate (2014). The economics of digital currencies, Bank of England Quarterly Bulletin, Vol. 54, No. 3, pp. 276-286.

Armantier, Olivier and Charles Holt (2019). Discount Window Stigma: An Experimental Investigation. Manuscript, NY Fed.

Arifovic, J., J. Duffy and J. Jiang (2019). Adoption of a New Payment Method: Theory and Experimental Evidence. Working paper, Simon Fraser University

Bordo, M. and A. T. Levin (2017). Central Bank Digital Currency and the Future of Monetary Policy. NBER Working Paper 23711.

Broadbent, B. (2016), Central banks and digital currencies, speech at London School of Economics on 2-3-2016, available at www.bankofengland.co.uk/publications/Pages/speeches/2016/886.aspx

Bigoni, M., Camera, G., and Casari, M. (2020) Money is More than Memory. *Journal of Monetary Economics*, 110, 99-115.

Bigoni, M., Camera, G., and Casari M. (2019). Partners or Strangers? Cooperation, monetary trade, and the choice of scale of interaction. *American Economic Journal: Microeconomics.*

Brown, P.M. (1996). Experimental evidence on money as a medium of exchange. *Journal of Economic Dynamics and Control* 20(4), 583-600

Boar, C. H. Holden and A. Wadsworth (2020). Impending arrival–a sequel to the survey on central bank digital currency. Bank of International Settlements Papers No. 107.

Camera, G., 2017. A perspective on electronic alternatives to traditional currencies. *Sveriges Riksbank Economic Review*, 1, 126-148.

Camera, G., Casari, M., and S. Bortolotti (2016). An experiment on retail payments systems. *Journal of Money, Credit and Banking* 48(2-3), 363-392.

Camera, G., and Casari, M. (2014). The Coordination Value of Monetary Exchange: Experimental Evidence. *American Economic Journal: Microeconomics*, 6 (1), 290-314.

Camera, G., Casari, M., and Bigoni, M. (2013). Money and trust among strangers. *Proceedings of the National Academy of Sciences*, 110(37), 14889-14893.

Camera, G., Goldberg, D., and Weiss, A. (2020). Endogenous market formation and monetary trade: an experiment. *Journal of the European Economic Association* 18(3).

Camera, G., C. Noussair, and S. Tucker (2003). Rate-of-return dominance and efficiency in an experimental economy. *Economic Theory* 22(3), 629-660.

Cœuré, B. and J. Loh (2018). Central bank digital currencies. CPMI Papers No. 174.

Duffy, John, and Frank Heineman (2020). Central Bank Reputation, Cheap Talk and Transparency as Substitutes for Commitment: Experimental Evidence. *Journal of Monetary Economics.*

Duffy, John, and Daniela Puzzello. 2014. Gift Exchange versus Monetary Exchange: Theory and Evidence. *American Economic Review* 104 (6), 1735-76.

Fischbacher, U. (2007). z-Tree: Zurich toolbox for ready-made economic experiments. *Experimental economics*, 10(2), 171-178.

Huber Juergen, Shubik Martin, Sunder Shyam (2014). Sufficiency of an Outside Bank and a Default Penalty to Support the Value of Fiat Money: Experimental Evidence. *Journal of Economic Dynamics and Control*, 47, 317-337

Hirota, S., J. Huber, S. Sunder, and T. Stoeckl (2020). Speculation, Money Supply and Price Indeterminacy in Financial Markets: An Experimental Study. *Journal of Economic Behavior and Organization.*

Kocherlakota, N.R. (1998). Money is memory. *Journal of Economic Theory*, 81, 232-251.

Kryvtsov, Oleksiy, and Luba Petersen (2020). Central Bank Communication that Works: Lessons from Lab Experiments. *Journal of Monetary Economics.*

Lucas, R.E., Jr. (1984). Money in a theory of finance. *Carnegie-Rochester Conference Series on Public Policy* 21, 9-46

Marimon Ramon, Sunder Shyam (1993). Indeterminacy of equilibria in a hyperinflationary world: some experimental evidence. *Econometrica*, 61, 1073-1107.

Roth, Alvin E., and Keith Murnighan (1978). Equilibrium Behavior and Repeated Play of the Prisoner's Dilemma. *Journal of Mathematical Psychology*, 17, 189-98.

Skingsley, Cecilia (2016), Should the Riksbank issue e-krona?, Speech at FinTech Stockholm on 16-11-2016.

Tobin, James (1985), Financial Innovation and Deregulation in Perspective, Bank of Japan Monetary and Economic Studies, Vol. 3, No. 2, pp. 19-29. Reprinted in Y. Suzuki and H. Yomo, eds., Financial Innovation and Monetary Policy: Asia and the West, Tokyo: University of Tokyo Press (1986), pp. 31-42.

Townsend, R. (1980). Models of money with spatially separated agents. In: Kareken, J., Wallace, N. (eds.) *Models of monetary economies*, 265-303. Minneapolis: Federal Reserve Bank of Minneapolis

Van Huyck, J. B., Battalio, R. C., and Beil, R. O. (1990). Tacit coordination games, strategic uncertainty, and coordination failure. *American Economic Review*, 80(1), 234-248.

A Appendix (for online publication only)

A.1 Experimental procedures

The experiment was conducted at the Economic Science Institute's laboratory at Chapman University and involved 504 undergraduate students that were recruited between 4/2017 and 4/2019. We ran 3 sessions per treatment, each with 24 participants all of whom had previous experience with a game similar to this one, but without tokens; participation in this earlier experiment varied from two months to two years earlier. Treatments have variation in self-reported sex composition between 29 and 48 percent males (average is 41%). At the session start, players were informed that only one of the five supergames completed would be randomly selected for payment, with public random draw at the end of the experiment. The points earned in that supergame would be converted into dollars according to a pre-announced conversion rate of USD 0.15. On average, participants were paid USD 27, including a show-up fee of USD 7 and the payoff from an incentivized quiz on the instructions that was taken before the start of the experiment. The average duration of a session was 1 hour and 20 minutes. Instructions were recorded in advance and played aloud at the beginning of a session, participants had the possibility to follow on individual copies. We used neutral language for the instructions (words like "cooperation" or "help" were never used). The experiment was programmed using the software z-Tree (Fischbacher, 2007). No eye contact was possible between participants. We collected demographic data in an anonymous survey at the end of each session.

A.2 Proof of Proposition 2

Consider economies with unit-token endowments and the start of any round $t \geq T$, without loss of generality. In equilibrium trade is possible in all meetings, but this may not be true off equilibrium, in which case the actions prescribed by the monetary strategy are clearly a best response. We must show that in equilibrium it is optimal for the producer to "sell" and for the consumer to "spend." To do so we consider unilateral one-time deviations by producer and consumer, on the equilibrium path.

Producers do not deviate in equilibrium Here we show that the producer optimally chooses "sell" if she is sufficiently patient. We calculate off-equilibrium payoffs using recursive arguments, given that the monetary trade strategy is history-invariant. A deviator's off-equilibrium payoff is largest when the deviation only alters the tokens' distribution for one round (the round after the deviation occurs). This is so because in this case players re-coordinate on equilibrium play very quickly after the deviation occurs. Given this assumption, we obtain a sufficient condition for monetary equilibrium.

Producer i has an incentive to help in exchange for a token if

$$d + \beta[d - l + \beta v_p(0)] < v_p(0 = a + \beta[u + g + \beta v_p(0)],$$

which holds whenever $\beta \geq \beta^*(u)$. To interpret the inequality note that we are considering the best-case scenario for the deviator, when the producer's initial defection pushes the distribution of tokens off equilibrium only in round $t+1$. She defects in t, which gives her payoff d instead of a, but she does not get a token. In $t+1$ she reverts back to following monetary trade, but now she is a consumer *without* money. Here, the token distribution is off equilibrium. Since everyone else also follows the monetary strategy, the outcome of her $t+1$ meeting is D and she earns $d - l$. In $t+2$, the deviator is again a producer without money. In the best-case scenario, in $t+2$ she meets a consumer with a token and so does every other producer. This best-case scenario occurs when the deviator meets her victim consecutively in two rounds, t and $t+1$. If so, in $t+2$ the tokens' distribution is back at equilibrium as all consumers have a token and producers have none. See the illustration in Table A1.

Table A1: The distribution of tokens off-equilibrium (best-case scenario)

	$t=1$	$t=2$	$t=3$	...
Initial producers	producer	consumer	producer	...
deviator	0	**0**	0	...
other player	0	1	0	...
other $n-2$ players	0	1	0	...
Initial consumers	consumer	producer	consumer	...
initial victim	1	**1**	1	...
other player	1	0	1	...
other $n-2$ players	1	0	1	...

Notes: The columns identify the player's role on a specific date. At the start of the game, initial producers have no tokens and initial consumers have one token each. This distribution corresponds to the equilibrium tokens distribution in any of the subsequent periods. The deviator is an initial producer who performs a one-time deviation in $t = 1$ by choosing D, and follows the monetary strategy thereafter. Off-equilibrium token holdings in $t = 2$ are in bold. The shaded cells identify who is in the match with the deviator in rounds $t = 1, 2$. In the best-case scenario, the deviator and her victim meet also in $t = 2$, which limits the spread of the deviation and brings the tokens distribution back to equilibrium in $t = 3$.

For the parameters selected, we have $\beta^*(u) = 0.55, 0.50, 0.46, 0.43$ for, respectively $u = -1, 0, 1, 2$.

It should be clear that off equilibrium if everyone follows the monetary strategy, then choosing D is a dominant action.

Consumers do not deviate in equilibrium. It is obvious that if tokens have no or a negative flow payoff, then spending them is optimal for a consumer in monetary equilibrium. This also holds if $u > 0$. To see this, consider the best case scenario in which the deviation of the consumer moves the distribution of tokens off equilibrium for just one round. A consumer with a token has an incentive to trade it for a good if

$$u + d - l + \beta[u + d + \beta v_c(1)] < v_c(1) = u + g + \beta[a + \beta v_c(1)],$$

which always holds because $u < l$ and $g > 2d$ by assumption. To interpret the inequality note that defecting in t gives payoff $u + d - l$ (instead of $u + g$) to the deviant consumer; she enters round $t + 1$ as a producer *with* money and reverts back to following monetary trade. The round following the deviation, she is a producer and since she has a token, then she chooses D, as specified by the monetary strategy. In the best-case scenario, in round $t + 1$ the deviator meets the person who experienced her initial defection. If so, then in $t + 2$ the tokens' distribution is back at equilibrium: all consumers have a token and producers have none. It follows that in equilibrium, refusing to spend a token is suboptimal for a consumer.

A.3 Measuring economic performance

We refer to *profit* as the points earned ex-post by a participant in the average round of a supergame. Profit excludes benefits or penalties from holding tokens (their distribution does not impact efficiency) and depend on the player's *cooperation rate* $c \in [0, 1]$, i.e., the relative frequency of cooperation as a producer, and the average frequency of cooperation C of the producers met.[16] Given role alternation, profit is (approximately) the average payoff in two

[16] Let $c_t = 1$ denote a cooperative outcome for a player who is a producer in period t (0, if defection). Let t_p be the number of periods in which this player was a producer in the supergame. The *cooperation rate* for this player is $\sum_{t=1}^{t_p} c_t/t_p \in [0, 1]$. A cooperative outcome can occur either with a unilateral transfer or a monetary trade.

consecutive rounds:

$$\pi(c, C) := \frac{1}{2}\left[3 + (1 - c)6 + 12C\right].$$

A consumer earns at least 3 points. A producer who cooperates gets 0, and 6 points otherwise—the term $(1 - c)6$. A consumer earns 12 points when the counterpart cooperates—the term $12C$. Hence, profit ranges from 1.5 to 10.5, is 7.5 points in the efficient outcome ($c = C = 1$) and 4.5 points in autarky ($c = C = 0$). The difference between *average* profit in the economy and autarky profits is realized surplus, and can be at most 3 points. Dividing realized surplus by its theoretical maximum gives *realized efficiency*, which is proportional to the average cooperation rate in the economy: it goes from 0% in autarky, to 100% under efficient play.

B Appendix (for online publication only)

B.1 Economies with two tokens per initial consumer

Proposition 3. *Consider an economy with $n \geq 2$ producers and n consumers. Let each initial consumer be endowed with 2 tokens. If*

$$\beta \geq \beta^*(0) = \frac{d - a}{g - d + l}, \tag{1}$$

then a monetary trade strategy exists that supports monetary equilibrium.

To prove the existence of monetary equilibrium we once again consider a time-invariant strategy. As before, all consumers choose "buy" any time they have some tokens, and otherwise they have no action to take. However, we adjust the monetary trading strategy for producers. Divide traders into two groups: group A is composed of all those who are initial consumers, group B is composed of all those who are initial producers; see Table A2. Producer B chooses "sell" in the initial round of play, and in all subsequent rounds does so only if all consumers A are believed to have 2 tokens and otherwise select "D." Producer A chooses "sell" only if all consumers B are believed to have 1 token, and otherwise select "D." It follows that in monetary equilibrium, every player alternates spending one token to selling for one token. Consequently, producers have 1 token, while producers B have 0 tokens; consumers A have 2 tokens, while consumers B have 1 token.

Table A2: Equilibrium token distribution .

Role in $t =$	Period t 1	2	3	4	5 ...
Players A	c	p	c	p	c
initial consumer	2	1	2	1	2 ...
other	2	1	2	1	2 ...
other $n-2$	2	1	2	1	2 ...
Players B	p	c	p	c	p
initial producer	0	1	0	1	0 ...
other	0	1	0	1	0 ...
other $n-2$	0	1	0	1	0 ...

Recall that players A are only matched to players B. The idea here is that "wealthy" players A should always maintain a 2-token balance as consumers, or monetary equilibrium will break down. Off equilibrium this could be easily supported if producers could see the consumer's exact token inventory—a producer B would simply not trade with a consumer A who has just 1 token. Since this is not possible, we address this issue by resorting to publicly available information about the distribution of tokens.

To do so, we specify a set of (self-fulfilling) beliefs off the monetary equilibrium path—which we did not do before. As before, in monetary equilibrium all players must believe that everyone will follow the monetary trading strategy in the continuation game. Instead, off-equilibrium players believe that tokens will no longer be accepted in the future. Since the number of meetings that resulted in trade is publicly revealed at the end of each round, this is sufficient to trigger the change in beliefs. To see this, consider a situation off equilibrium. Trying to spend a token is always optimal, so the monetary strategy is a best response for a consumer. However, selling for a token is suboptimal for producers because now tokens are believed to be no longer accepted. This belief is clearly self-fulfilling. Hence, the monetary strategy is a best response for a producer off-equilibrium.

Now we show a condition ensuring that deviating in equilibrium is unprofitable. For a consumer, the monetary strategy choice dominates any other choice. Now consider a producer. Without loss in generality consider producer A—who has one token in equilibrium. This producer has the greatest incentive to deviate because she has a token to spend next round even if she does not produce today (a producer B does not have this luxury). For concreteness, let $t = 2$ and suppose producer A deviates by choosing D. She reverts back to play the monetary strategy in $t = 3$. By doing so, in $t = 2$ she earns d instead of $a < d$, and in $t = 3$ she has one token to spend. Since her deviation changes the distribution of tokens, beliefs will change hence from $t = 3$ on she (and everyone else) will be unable to spend tokens. It follows deviating in equilibrium is suboptimal for a producer A if

$$d + \beta\frac{d - l + \beta d}{1 - \beta^2} \leq v_0 = \frac{a + \beta g}{1 - \beta^2} \qquad \Rightarrow \qquad \beta \geq \beta^*(0) = \frac{d - a}{g - d + l}.$$

Notice that this is the same condition we found under the monetary trading strategy. It is the same because the deviator is punished as quickly and as effectively in both cases.

B.2 Additional tables

Table A3: Outcomes in FIAT (meetings where trade is possible).

Dep. var.:	(1) Monetary Trade		(2) Gift		(3) Spend		(4) Sell	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Supergame	0.052***	(0.004)	-0.014***	(0.005)	0.039***	(0.001)	0.042**	(0.018)
Controls	Yes		Yes		Yes		Yes	
Constant	0.303***	(0.039)	0.068***	(0.020)	0.753***	(0.055)	0.435***	(0.052)
N	360		358		343		358	
R^2 within	0.109		0.079		0.160		0.060	
R^2 between	0.129		0.011		0.062		0.095	
R^2 overall	0.117		0.059		0.109		0.083	

Notes: Panel regression with random effects at the individual level and robust standard errors (S.E.) adjusted for clustering at the session level. One obs.=one subject in a supergame 1-5, rounds 1-16 only. *Controls* include duration of the previous supergame, self-reported sex, and two measures of understanding of instructions (response time and wrong answers in the quiz). Symbols $***$, $**$, and $*$ indicate significance at the 1%, 5% and 10% level, respectively.