

8-14-2022

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Camera, G. (2022). Introducing new forms of digital money: Evidence from the laboratory. *ESI Working Paper 22-11*. https://digitalcommons.chapman.edu/esi_working_papers/372/

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Introducing New Forms of Digital Money: Evidence from the Laboratory

Comments

ESI Working Paper 22-11

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

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August 14, 2022

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. In the experiment, 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 provide insights for payments systems innovation and policy design.

Keywords: digital currency, endogenous institutions, repeated games, CBDC.

JEL codes: C70, C90, E04, E05

* I thank for several helpful comments two anonymous reviewers, Co-Editor S. Chugh, as well as seminar participants at the 2019 Conference on the Economics of Central Bank Digital Currency, Society of Experimental Finance Winter Conference 2020, Virginia Tech., University of Hamburg, University of Heidelberg, L. Bitter, and Y. Xu. I thank O. Enquist for help in running pilots and M. Luetje for laboratory help. Correspondence address: Gabriele Camera, Professor of Economics and Finance, Economic Science Institute, Chapman University, One University Dr., Orange, CA 92866; e-mail: camera@chapman.edu.

1 Introduction

Many central banks are considering issuing currency in an entirely digital form, known as CBDC (Boar et al., 2020; Camera, 2017). The goal is to replace or complement coins and banknotes—the sovereign monetary instruments that currently support retail payments. 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 reports results of an experiment that investigates how allocative efficiency supported by the exchange of tokens depends on the flow payoff from holding tokens. It documents outcomes observed in laboratory economies where a “sophisticated” interest-bearing token replaces or complements 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 mone-

¹Central Bank currency should not be confused with bank deposits, denominated in the same unit and typically carrying 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) their exchange is not peer-to-peer but 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). A CBDC could also raise payments systems’ efficiency by reducing the costly layers of financial institutions that support the processing and settlement of electronic payments, and could improve the speed and efficacy of intervention through the monetary transmission channel. See for instance Broadbent (2016); Skingsley (2016).

tary models, 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 a socially efficient intertemporal exchange of goods. Pareto-inferior equilibria also exist, with partial or even no production at all. To facilitate efficient play, initial consumers are endowed with a fixed supply of tokens with no intrinsic or redemption value, and no link to outside currencies—i.e., “plain” tokens. If participants spontaneously trade production for a token, then a monetary system emerges where tokens acquire value as payment instruments—a fiat currency is born.

This baseline condition is contrasted to treatments with “sophisticated” tokens that can yield small payoffs, positive or negative, i.e, are interest-bearing. Several economies are studied: with just one type of token, two types of tokens, or where a plain tokens endowment is replaced by sophisticated ones. By design, using tokens as a money can support efficient play in all treatments, though it is not necessary as a non-monetary strategy can also achieve that goal. 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 be-

tween 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 findings (Camera et al., 2013). A novel result is that while participants learned to exchange plain tokens for production, 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. Giving tokens a small negative yield sharply reduced their acceptability and, hence, their value 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. Our laboratory economies performed best in a zero-interest rate environment. This provides useful information for Central Banks considering digital currencies with interest-bearing features 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. Small *intrinsic* values of interest-bearing tokens distorted decision-making, fostering myopic conduct that reduced subjects’ appreciation for the large potential *extrinsic* value of tokens as a medium of exchange.

From a methodological perspective, the study brings to light the advantage of combining theoretical with experimental investigation to provide insights that may help 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 the laboratory. This contributes to a growing body of knowledge showing that exploring behavioral

angles can improve overall policy assessment (Armantier and Holt, 2019; Duffy and Heinemann, 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 tradeoff 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. Typically, experiments study traditional fiat monetary systems and commodity money. This experiment widens the focus to study the performance of possible alternatives to traditional currencies—for which Central Banks have obvious field data limitations.

In early experiments, monetary trade was taken as a primitive, meaning

that participants *must* trade with a pre-defined instrument to earn income (e.g., Marimon and Sunder, 1993). Camera and Casari (2014) and Camera et al. (2013) innovated with a design based on a game-theoretic framework where monetary trade emerges spontaneously, being neither imposed nor necessary to maximize payoffs. Here, we build on that second strand of literature by considering digital tokens that are more sophisticated than traditional currencies—the intrinsically useless objects that are typically studied in the laboratory (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 give some context, this study is part of a wider research agenda investigating possible links between the emergence of monetary systems, market organization, and economic development. In particular, it is related to three recent articles about how monetary systems affect the endogenous size of trading groups (Bigoni et al., 2019), the performance of reputation systems relative to monetary systems (Bigoni et al., 2020), and the competition between synchronous and asynchronous trading systems (Camera et al., 2020).² Our design pushes this research frontier forward by focusing on the impact

²A 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.

of currency innovation on economic organization. We consider sophisticated tokens that are theoretically preferable relative to traditional currency instruments, as holding them yields a direct benefit. However, monetary trade is not imposed as a necessary mechanism to generate income: alternatives to monetary exchange exist. This sets the experiment apart from those few on the theme of currency innovation, which all preclude alternatives to monetary exchange. In Camera et al. (2003), buyers must choose between spending cash or a dividend-bearing perpetuity, in Camera et al. (2016) traders must choose between a plain cash instrument or a better-performing electronic money, and similarly in Arifovic et al. (2021). 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 is unnecessary to attain it since 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 experimental design reflects this principle and makes explicit the trading process, and builds on Camera and Casari (2014). An economy consists of eight players who interact for an indefinite number of rounds (or, periods). Half are consumers, half are producers, and everyone switches role in every round as in a Turnpike (Townsend, 1980). In the baseline treatment, every initial consumer is endowed with one plain “token,” a riskless electronic object that has no intrinsic value, is indivisible, and can be exchanged peer-to-peer. Tokens have no reference to outside currencies, cannot be redeemed for points or cash, and

cannot be disposed of so their supply of four units is stable. Subjects are free to use or ignore tokens so that whether or not tokens circulate and become a valuable currency in the experiment is endogenous.

A round of play. Interactions are in random producer-consumer pairs. Every round, each pair faces the game in Table 2. The producer has 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: The stage game in a meeting where the consumer has tokens.

		Producer		
		D	C	Sell
Consumer	Idle	3, 6	15, 0	3, 6
	Spend	3, 6	\textcircled{T} 15, 0	\textcircled{T} 15, 0

Notes: Payoffs to Consumer, Producer, in points. \textcircled{T} = token exchanged from consumer to producer. Monetary trade occurs when **Sell** and **Spend** are selected. The shaded cells refer to the restricted game if monetary trade is impossible (the consumer has no token). Neutral language described choices in the experiment (see Instructions in Supp. Mat.).

Table 2 shows outcomes as a function of actions 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 with tokens can offer one for the producer’s good (**Spend**) or take no action (**Idle**). Consumers without tokens have no action to take: the outcome depends on the producer’s D or C

choice (shaded cells). Possession of tokens is known to counterparts, but not the exact amount, to preclude identification and reputation-building.

Players move simultaneously—hence, 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 (indicated by \textcircled{T} in Table 2), 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). Subjects see the outcome *and* the counterpart’s action at the end of the meeting.

A consumer exiting a meeting without a good earns $d - l = 3$ points (in the experiment 1 point = USD 0.15), while a producer in a similar situation earns $a = 0$ points. Total earnings in a pair are 15 or 9 points, depending on who consumes (consumer or producer). Hence, producers can create a 6-points surplus by giving their good to consumers. Token exchange is unnecessary to create this surplus as the distribution of tokens in the pair neither affects the payoff matrix, nor prevents the selection of C. Given the payoff structure, self-interested producers must have a prospect of future consumption to be willing to give up their good. 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 0.25 probability of the economy ending, using a computer’s random draw from a uniform probability dis-

³Limiting the exchange to one token 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.

tribution. 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.

With each new 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 are informed about the number of cooperative outcomes in the entire economy. Each session includes 24 players arranged in three distinct economies, which 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 known to subjects. Overall, a session generates data for 15 economies, with each subject participating in five different economies.

Treatments. The payoff structure of Table 2 is common to all treatments, which differ either in the tokens’ type or supply (or both); see Table 3. In some treatments, holding a token at the start of a round creates a small gain or loss denoted u (in points). A token is *plain* if $u = 0$ and *sophisticated*, otherwise. In the baseline FIAT treatment, tokens are plain, and there is a constant 4 unit supply (one per initial consumer). The treatments PENALTY, REWARD, and REWARD2 consider sophisticated tokens with small flow payoffs $u = -1, 1, 2$,

⁴This 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.

respectively.⁵ We call u the *interest* paid by tokens.

Table 3: Treatments.

Treatments	Interest u		Token
	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; here the game is still represented by Table 2. 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 adding one choice per player (use one token, or use the other). This is described in Appendix A, Section A.1, where further details about the design and experimental procedures are also found. Finally, in SWITCH the first two supergames are as is in FIAT, while 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).⁶ Because $-l < u < l$, total payoffs in a pair are positive in all treatments since $2d - l + u > 2(d - l) > 0$.

⁵A design where u is paid in tokens generates an unstable token supply (unlike the FIAT baseline), distorting economic incentives for monetary trade (the “liquidity” value of tokens as medium of exchange), and also adding unnecessary complexity to the experiment.

⁶Subjects were informed that the first two supergames involved plain “white tickets,” which would be replaced by fancier “yellow tickets” described in detail before supergame 3.

4 A theoretical reference

Our setup captures two key aspects of the theory of money: (i) money enables an intertemporal reallocation of consumption that benefits everyone but is difficult to accomplish due to trade frictions; (ii) monetary exchange is not imposed and, as alternative non-monetary arrangements are also possible, it emerges endogenously as an optimal response to trade frictions.

In the experiment a strategy exists that supports the efficient allocation and is not based on using of tokens as a money, i.e., the playing field is theoretically level. 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 tokens' flow payoff u . Two 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

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

Here, the tokens' flow payoff u affects only initial consumers, as tokens never change hands. Autarky is a subgame perfect equilibrium because D is always a best response to everyone playing D. How can we support efficient play?

A non-monetary arrangement for efficient play. Suppose tokens are ignored and never change hands. In the efficient outcome payoffs are

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

Efficient play is supported as a subgame perfect 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. Deviating to D in equilibrium is suboptimal when $v_p \geq \hat{v}_p$, i.e., when the continuation probability $\beta \geq \beta^* := \frac{d-a}{g-d+l}$. This holds in the experiment since $\beta^* = 0.5 < \beta = 0.75$.⁷

Proposition 1. *In all treatments, a non-monetary strategy exists that supports the efficient allocation as a subgame perfect 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. 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 trade 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 and consider the *monetary trade strategy*. In any round and after any history of play: (i) as a consumer, the player chooses **Spend** if she has tokens, or else has no action to take; (ii) as a producer, she chooses **Sell** if she has no tokens and the consumer has some (= monetary trade

⁷There 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).

is possible). In all other circumstances, the producer chooses D.⁸ 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 because each consumer has 1 token, and each producer has 0. A token is exchanged quid-pro-quo for one good in all rounds, in every pair. This supports the efficient reallocation of goods, and also redistributes the flow payoff u —without social efficiency implications. In monetary equilibrium the payoff to initial producer and consumer are

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

Proposition 2. *If $\beta \geq \beta^*(u) := \frac{d - a}{u + g - d + l}$, then monetary trade is a subgame perfect equilibrium when initial consumers have 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 sufficient condition for the existence of monetary equilibrium hinges on 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

⁸Unlike the non-monetary trigger strategy, the monetary strategy is Markov and history-independent, so it does not require information about others’ histories of play. It also does not rely on a threat of community punishment to deter equilibrium deviations. Finally, it does not prescribe a change in behavior off-equilibrium and—unlike the trigger strategy—it supports some cooperation off-equilibrium: as off-equilibrium some consumers may have no tokens, not all meetings allow monetary trade, hence trade occurs only in pairs where the consumer has tokens and the producer has none, and 100% efficiency cannot be attained.

this reason, monetary trade is incentive-compatible off-equilibrium, also.

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 for 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 when $u < 0$. Hence, the threshold $\beta^*(u)$ declines in u , $\beta^*(u) = 0.55, 0.50, 0.46, 0.43$ for, respectively $u = -1, 0, 1, 2$. This discussion extends to MIX and, with some adjustment, to FIAT2.⁹

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), and of a *gift* when they follow the non-monetary strategy (Idle and C). Monetary trade and gifts generate the same cooperation level and surplus. Cooperation can also result from the actions Spend and C, but this outcome is inconsistent with either strategy. Monetary equilibrium is supported on a larger set of parameters as u increases. This suggests:

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.*

⁹In MIX, players can ignore one type of token and trade the other. 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 Section B.1 in Supp. Mat.

Existence of monetary equilibrium depends on producers' economic incentives. If they benefit from selling for a token to reap the future benefit g , then consumers surely desire to spend tokens as they benefit immediately.¹⁰ Also, there is no economic incentive to produce for a token and hoard it forever after because $d \geq \beta u / (1 - \beta)$ for all $u \leq 2$.¹¹ This suggests:

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

Finally, theory suggests that tokens should not circulate because efficiency can be attained without exchanging them (Proposition 1). If so, the frequency of monetary trade should not decline when benefit-yielding tokens are present. However, prior experiments *do* show that monetary trade emerges because their use facilitates coordination on efficient play (Bigoni et al., 2019; Camera and Casari, 2014). Hence, we put forward the following:

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

The reason is that if both kinds of tokens are present (as in MIX), this neither removes the equilibria available in FIAT, nor prevents the use of plain tokens. An equilibrium exists in which plain tokens circulate as money, while benefit-yielding tokens are hoarded; see Camera et al. (2003) for experimental evidence on this Gresham's Law type of outcomes. Instead, if benefit-yielding tokens replace plain tokens (as in SWITCH), then the economic incentives for monetary trade should become stronger (Proposition 2).

¹⁰This 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.

¹¹Section B.2 in Supp. Mat. discusses in more depth the issue of hoarding.

5 Results

It is helpful to give an overview by investigating the empirical relation between incidence of monetary trade and economic performance in the experiment.¹² Let *profit* denote the points earned by a participant in the average meeting (excluding earnings from holding tokens). It ranges from 1.5 to 10.5 points, 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 average cooperation in the economy, ranging from 0% in autarky, to 100% under full cooperation.

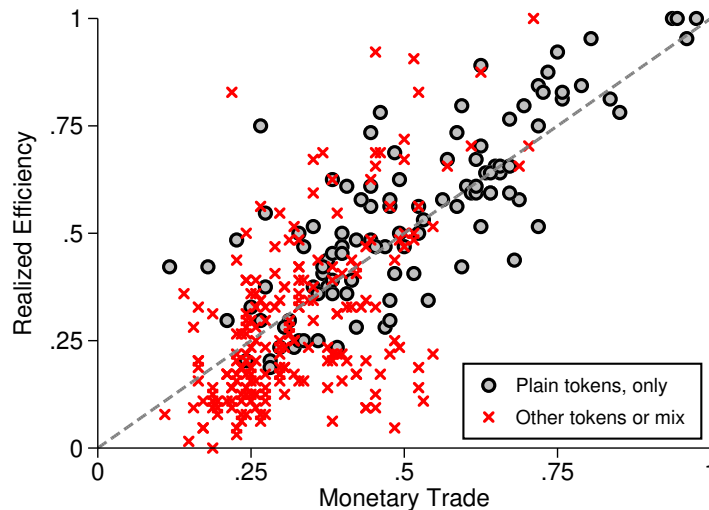
Result 1. *There is a positive association between realized efficiency and the frequency of monetary trade.*

Fig. 1 plots realized efficiency in an economy, against the frequency of monetary trade (all meetings). This frequency depends directly on choices in meetings where the consumer has tokens (monetary trade is *possible*), and indirectly on the tokens' distribution resulting from those choices, which determines how frequently trade is impossible in a meeting (0.39, all treatments).

The correlation between monetary trade and efficiency is 0.754. A one standard deviation increment in the frequency of monetary trade is associated with an efficiency increment of about 19 percentage points; see Supp. Mat., Table B2. This positive association confirms earlier results for economies of strangers (e.g, 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.

¹²To reduce noise and enhance comparability across sessions, the analysis focuses on rounds 1-16, which are common to all supergames. Supergames lasted 19.6 rounds on average (min. 16, max. 32) with a standard deviation of 4.2.

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



Notes: One obs.=one economy (all meetings in rounds 1-16), all treatments ($N = 315$).

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.¹³ 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 monetary trade was feasible—seen especially in sophisticated-tokens economies.

¹³The 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 Supp. Mat., Fig. B1.

Hence, not all tokens seem equally suitable for supporting efficient play. The question is why. Did some tokens slow or prevent the development of a monetary system, and why? To offer an answer we study outcomes and individual behavior with different types of tokens.

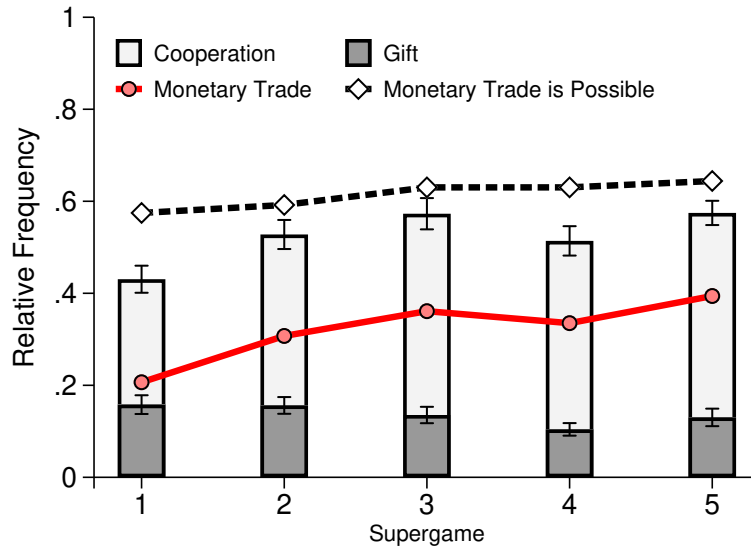
5.1 Plain tokens facilitate monetary trade

Participants in FIAT economies learned to coordinate on efficient play by increasingly relying on tokens' exchange.

Result 2. *In FIAT economies monetary trade supported efficient play, and increased as participants gained experience with the task*

Fig. 2 reports the relative frequency of outcomes experienced by the average subject in a supergame (all meetings).

Figure 2: Outcomes for Average Subject of FIAT.



Notes: One obs.=one subject in a supergame, all meetings of rounds 1-16 ($N = 72$ per supergame). The whiskers identify the standard error of the mean frequency (markers).

A meeting can result in *Cooperation* or *Defection*. Cooperation can be supported by *Monetary Trade*, or by a *Gift* if the producer unconditionally cooperates (C) and does not receive a token. Cooperation was primarily supported by monetary trade because this strategy gives the subject greater control over outcomes, it mitigates strategic uncertainty and facilitates coordination on efficient play (Camera and Casari, 2014; Camera et al., 2013).¹⁴ Monetary trade almost doubled from 0.21 to 0.39 during the session, while the frequency of gifts remained low. This increased cooperation from 0.43 in supergame 1 to 0.57 in supergame 5. Yet, we do not observe full cooperation; the primary reason is that tokens did not optimally circulate due to heterogeneous behavior; for instance, about 8% of participants always chose D as producers. Hence, consumers did not always have a token; on average monetary trade was possible in about 60% of meetings (dashed line in Fig. 2).

The significance of these findings is established by panel regressions; see Supp. Mat., Table B3. Players learned to coordinate on monetary trade and avoided non-monetary norms of mutual support: cooperation improved thanks to increased exchange of tokens, not gifts. This greater circulation of tokens had a positive self-reinforcing effect, making trade possible in more meetings, which supported more cooperation. A one standard deviation increase in the frequency of meetings where trade is possible raised cooperation by about 11 percentage points, and decreased the frequency of gifts by about 7 percentage points. Yet, acceptability problems did not get fully resolved during a session, which contributed to limit the exchange value of tokens by keeping their distribution off equilibrium and, hence, cooperation below 100%.

The constraining impact of this “illiquidity” on efficient play becomes apparent if we study meetings where monetary trade was possible; see Supp.

¹⁴In 0.07 meetings a token was exchanged without the producer requesting it (C and Sell).

Mat., Table B4. There, gift-giving outcomes were close to zero, while monetary trade almost doubled between start and end of a session. 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. They learned that offering tokens could raise the chance of a cooperative outcome—hence they increasingly did so as the session progressed (the frequency of **Spend** is close to 1 by supergame 4)—and, consequently, more frequently demanded tokens. Still, the frequency of **Sell** remained below the **Spend** frequency, betraying an acceptability problem. This constrained the growth in monetary trade and, hence, cooperation.¹⁵ A way to mitigate acceptability problems is to make tokens more economically enticing. Could benefit-yielding tokens improve outcomes? We offer an answer by studying economies exclusively endowed with “sophisticated” tokens.

5.2 Sophisticated tokens hinder monetary trade

Consider **PENALTY**, **REWARD**, and **REWARD2**, which replace plain with sophisticated tokens with holding flows $u = -1, 1, 2$, respectively. Everything else is as in **FIAT**.

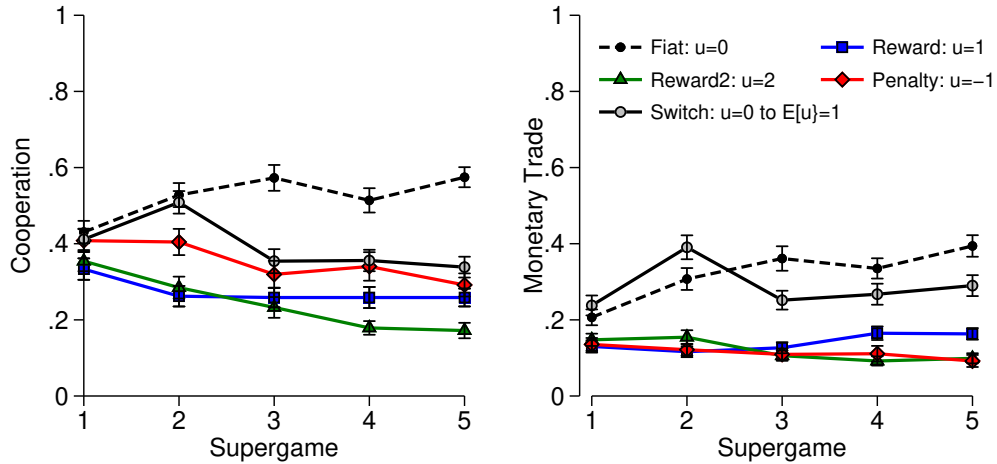
Result 3. *Substituting plain with sophisticated tokens lowered cooperation.*

The left panel in Fig. 3 shows the evolution of cooperation (equivalently, realized efficiency) during the average session, by treatment. Average cooperation in supergame 1 is similar across treatments, a similarity that 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 level in **FIAT**. This cooperation

¹⁵For the significance of these observations see Supp. Mat., Table B5.

decline 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).

Figure 3: Outcomes for Average Subject in One-Token Economies.



Notes: See notes to Fig. 2. FIAT added as a comparison.

The panel regression in Table 4 provides additional evidence. None of the treatment coefficients in col. 1 is statistically significant, suggesting that inexperienced subjects behaved similarly across treatments (confirmed by a regression on supergame 1 data, 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 highly significant for PENALTY and REWARD2, insignificant for REWARD). In summary, in economies endowed with sophisticated tokens something interfered with participants' ability to learn to coordinate on efficient play. Not only cooperation did not improve when to-

kens generated positive income flows, but it progressively declined during the session, which is opposite of what happened in plain-token economies. The cause of this failure is discussed next.

Table 4: The Impact of Sophisticated Tokens.

Dep. var.:	(1) Cooperation		(2) Gift		(3) Monetary Trade	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Trade Possible	0.080***	(0.021)	-0.044***	(0.009)		
<i>Treatment</i>						
Penalty	-0.007	(0.089)	-0.001	(0.057)	-0.055	(0.041)
Reward	-0.122	(0.083)	-0.006	(0.061)	-0.093**	(0.041)
Reward2	-0.046	(0.082)	-0.006	(0.059)	-0.024	(0.039)
Game	0.020	(0.013)	-0.007	(0.009)	0.040***	(0.001)
Penalty \times Game	-0.045**	(0.020)	-0.006	(0.010)	-0.050***	(0.007)
Reward \times Game	-0.031	(0.020)	-0.014	(0.010)	-0.029***	(0.009)
Reward2 \times Game	-0.060***	(0.013)	-0.016*	(0.010)	-0.056***	(0.004)
Controls	Yes		Yes		Yes	
Constant	0.422***	(0.068)	0.168***	(0.054)	0.183***	(0.030)
N	1440		1440		1440	
R ² within	0.163		0.169		0.063	
R ² between	0.415		0.073		0.426	
R ² overall	0.303		0.130		0.255	

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 (all meetings, rounds 1-16). *Treatment* indicators take value 1 in the respective treatment, else 0 (*Fiat* serves as the basis of the regression). *Game* is a continuous regressor taking values 1-5. *Controls* include duration of 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.

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

Evidence is in the right panel of Fig. 3 and cols. 2-3 in Table 4. 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 of 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 4, where the *Treatment* coefficients are all negative (significant only for $u = 1$) 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, we cannot reject H2: when $u = -1$ tokens supported significantly less monetary trade than $u = 0$.

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 $u = -1, 0, 1, 2$) and gifts did not increase during the session. In col. 2 of Table 4, the coefficients on treatment and their interaction with *Game* are all negative, often significantly different from zero. Summing up, endowing an economy with sophisticated tokens precluded the spontaneous emergence of a monetary system. To understand why this happened we study individual choices.

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

Theoretically, the choice **Spend** should be at least as frequent as **Sell** because in monetary equilibrium incentive compatibility constraints are slacker for consumers than producers (see Section 4). Table 5 displays the average frequency of these two choices in meetings where monetary trade was possible. As compared to FIAT, the frequency of **Sell** improved when holding tokens

carried a 2-point benefit, while it sharply declined with a 1-point penalty.

Table 5: Meetings where Trade is Possible

Treatment	Choices		Outcomes		
	Spend	Sell	Mon. Trade	Gift	Share
PENALTY	0.88	0.23	0.20	0.02	0.55
FIAT	0.86	0.59	0.51	0.01	0.61
REWARD	0.48	0.62	0.30	0.03	0.51
REWARD2	0.41	0.70	0.28	0.03	0.5
FIAT2	0.89	0.53	0.49	0.02	0.83
MIX	0.68	0.54	0.21	0.03	0.68
SWITCH	0.75	0.68	0.51	0.01	0.56

Notes: One obs.: one subject in a supergame, meetings where trade is possible of rounds 1-16. *Choices:* relative frequency of *Sell* choice (as a producer in the supergame), and *Spend* choice (as a consumer). *Outcomes:* relative frequency of *Monetary Trade* and *Gift*. *Share:* overall share of meetings in which trade was possible (the consumer had tokens; MIX includes all meetings where consumers had at least one type of token).

To establish the significance of these observations we study how treatments affected the distribution of producers' choices when monetary trade was possible using a multinomial logit model because the three actions available—D, C and Sell—have no natural ordering. Table 6 reports marginal effects.

Table 6: Producer's choices when monetary trade is possible (marginal effects).

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

Notes: Multinomial logit regression on producer's choices. One obs.=one producer in a meeting where trade is possible, rounds 1-16. Data from Fiat (the base of the regression), Reward, Reward2, and Penalty ($N = 6265$). Robust standard errors adjusted for clustering at session level. The model includes a supergame regressor interacted with treatments, indicator variables for each round 1-16, and standard controls (not reported). Symbols ***, **, and * indicate significance at the 1%, 5% and 10% level, respectively.

A one-point penalty from holding tokens significantly lowers the demand for tokens (*Sell*) by 0.35 points and increases the probability of D by 0.25 (see the *Penalty* coefficients). A two-point reward causes the opposite shift: the probability of *Sell* increases by 16 percentage points, while that of unconditional defection falls by 9. Instead, a one-point reward induces a small and statistically insignificant increase in acceptance probability (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 emerging in PENALTY. But what explains the lack of monetary trade when holding tokens yielded benefits? There, producers' demand for tokens *increased* relative to FIAT but consumers hoarded them; see col. *Spend* in Table 5. The significance of these observations is established by a logit regression about consumer choices in meetings where trade was possible; marginal effects are in Table 7.

Table 7: Hoarding if Trade is Possible and Gifts if Trade is Impossible.

Dep. var.: choice	(1) Consumer chooses SPEND (trade is possible)		(2) Producer chooses C (trade is 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: Marginal effects from Logit regression on consumer's choices (if trade is possible), and producer's choices (if trade is impossible). One obs.=one subject in a round 1-16. Data from FIAT (the base of the regression), REWARD, REWARD2, and PENALTY. Robust standard errors adjusted for clustering at session level. Reg. (1): dependent variable is 1 if the consumer chooses SPEND, 0 otherwise. Reg. (2): dependent variable is 1 if the producer chooses C, 0 otherwise. We also include a supergame regressor interacted with treatment, dummies for each round 1-16, and standard controls (not reported). Symbols ***, **, and * indicate significance at the 1%, 5% and 10% level, respectively.

Consumers were significantly less likely to spend benefit-yielding tokens (40 and 49 percentage points, for REWARD and REWARD2). Instead, introducing a holding penalty did not increase the probability to spend them relative to plain tokens (see the *Penalty* coefficient). Based on this evidence H3 is rejected for treatments with $u = 1, 2$, but not $u = -1, 0$ where hoarding of tokens did not occur (consistent with theory). Given these acceptability and hoarding problems, did players try to establish an alternative cooperative norm based on gifts? The answer is negative. Gifts did not increase as compared to FIAT; see Table 5 and the treatment coefficients in Tables 6 and 7 for meetings where trade was possible and impossible, respectively.

The conclusion that plain tokens performed as a better money than sophisticated tokens can be further qualified by calculating a “liquidity value” of tokens, i.e., the value linked to their use as a means of payment. This value is an indirect flow payoff, a rough measure of which is the difference between the income expected by a consumer entering a meeting with some tokens as opposed to none. The liquidity value is largest when tokens reduce strategic uncertainty because offering them is likely to result in cooperation. In monetary equilibrium the liquidity value of the first token is greater than a second token (which should be zero, as only one token is needed to support efficient play), so the incentive to trade is largest for a token-less producer. If tokens have primarily a liquidity value in the experiment, then we should observe cooperation rates that decline in the producer’s token holdings.

Table 8, which reports cooperation rates conditional on token holdings in a meeting—as we move away from plain tokens to a 1-point penalty and reward—confirms this prediction. The data in this table can also be used to determine a rough liquidity value measure of tokens (the calculations are in Appendix A, Section A.4), which turns out to be twice as large in FIAT

as compared to the other two treatments. The reasons is that cooperation was highest in FIAT as compared to he other two treatments, in every meeting where trade was possible; in other words, plain tokens reduced strategic uncertainty the most.

Table 8: Distribution of token holdings and associated cooperation.

Producer holdings	Consumer holdings					
	Penalty		Fiat		Reward	
	0	1 +	0	1 +	0	1 +
0	23 (0.28)	44 (0.43)	25 (0.36)	49 (0.68)	27 (0.23)	38 (0.37)
1+	22 (0.26)	11(0.29)	14 (0.28)	12 (0.49)	22 (0.13)	14 (0.31)

Notes: Unit of obs.: one meeting in round 1-16 ($N = 2,880$ per treatment). 0= participant starts the meeting without a token. 1+= participant starts the meeting with 1 or more tokens (accumulation of 2 or more tokens was infrequent, around 10% to 12%). The cells report the share of meetings and the cooperation rate in those meetings (in parentheses).

Summing up, endowing an economy with benefit-yielding instead of plain tokens significantly reduced cooperation and efficiency because it stunted the development of a monetary trade convention. Could this be reversed if participants were given the freedom to select between sophisticated or plain tokens, as a monetary instrument? This possibility is investigated next.

5.3 Economies with competing tokens

In MIX initial consumers have one plain *as well as* one benefit-yielding token $u = 2$. This allows a choice of token which expands their choice set. Participants see what tokens can be traded, if any (not the exact quantity), and can only select one token type to trade (if two are available). After choosing, outcome and counterpart's choice are revealed. A token is transferred only if both choices are mutually compatible. For instance, if a producer demands a sophisticated token and the consumer offers a plain token, then there is neither

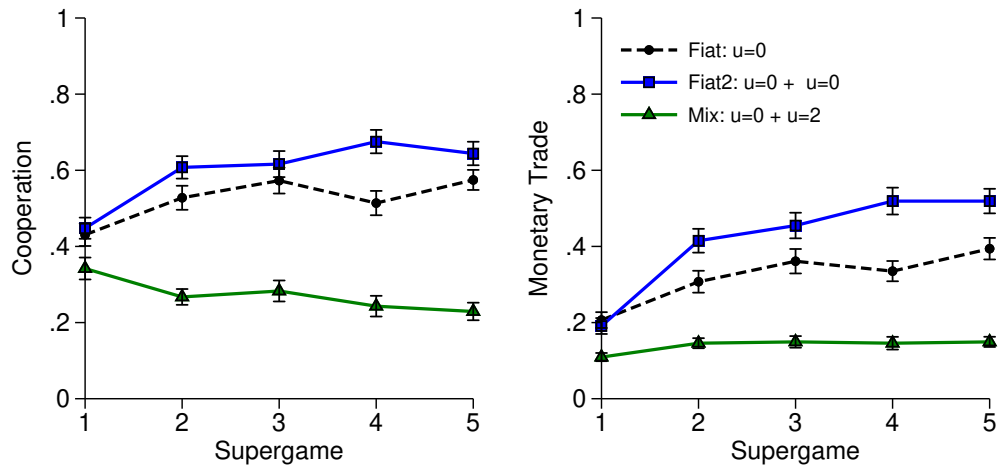
cooperation nor a token transfer. Failed trades cannot be re-attempted with another token; more details are in Appendix A, Section A.1.

In FIAT2 initial consumers have two plain tokens each. Hence, both MIX and FIAT2 economies could support the trade of plain tokens, similarly to what we observed in FIAT.

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

Fig. 4 shows that in MIX cooperation starts at levels similar to FIAT, but then steadily declines because participants did not learn to exchange tokens. Trade (with any token) averaged 14%, well below FIAT levels. Gifts were also less frequent (0.06 vs. 0.15 in FIAT). The panel regressions in Supp. Mat., Table B6, establish the significance of these observations.

Figure 4: Outcomes for Average Subject of FIAT2 and MIX.



Notes: See notes to Fig. 2. FIAT added as a comparison.

Is it possible that doubling the number of tokens in MIX reduced the in-

centives to cooperate by increasing the number of meetings where trade was possible? We can reject this hypothesis. First, in FIAT cooperation increased in the frequency of meetings where trade was possible (see Table 4). Second, if we consider FIAT2—which has twice the FIAT token supply—we see that monetary trade grew faster than in FIAT (Fig. 4). Doubling the plain token supply made monetary trade possible in 83% of meetings vs. 61% in FIAT (Table 5). This *boosted* monetary trade and cooperation, something we do not observe in MIX. In FIAT2 participants learned to coordinate on trading cooperation for a plain token much as they did in FIAT. In fact, monetary trade and cooperation increased significantly more during the session than in FIAT. Table B6 in Supp. Mat. provides econometric evidence.¹⁶

Result 2 is thus robust to doubling the plain tokens supply, and Results 3-4 are robust to adding benefit-yielding tokens alongside plain ones. As efficiency levels were lower in MIX than FIAT2, H4 can be rejected. This result is surprising because subjects could have coordinated on trading with plain tokens—FIAT shows they were capable of doing so. Yet, giving them a choice between plain and benefit-yielding tokens exacerbated the acceptability problems seen in FIAT, without resolving the hoarding problems seen in REWARD2.

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.*

Participants in MIX infrequently traded when it was possible, independent of the consumer’s portfolio. Three observations from Table 9, which reports

¹⁶By contrast, gifts declined in FIAT2, from 15% at the session start to 3% at the end. Overall, gifts occurred in 7% of meetings, which is half of FIAT. This suggests that producers might have made gifts to token-less consumers primarily to overcome illiquidity problems outside of their control. Indeed, in FIAT2 the larger token supply reduced the probability that being token-less was due to a shortage of tokens.

choices in meetings where *some* token could be exchanged, stand out.

Table 9: Distribution of choices in a meeting of MIX.

Token(s) held by consumer	Consumer's Choice			Producer's Choice			
	Keep token(s)	Spend Soph.	Spend Plain	D	C	Sell for Soph.	Sell for Plain
None (32%)	–	–	–	0.79	0.21	–	–
Plain only (17%)	0.14	–	0.86	0.60	0.14	–	0.26
Sophisticated only (19%)	0.67	0.33	–	0.29	0.06	0.64	–
Both types (32%)	0.19	0.23	0.58	0.21	0.09	0.60	0.10

Notes: Unit of obs.: one meeting in a period (rounds 1-16). The relative frequency of choices reported is conditional on the consumer's token holdings (the share of each possible portfolio is in parentheses). A dash “–” indicates that the choice was not available. For each portfolio, the sum of choices of a consumer (producer) sums up to 1. *None*: meetings where trade is not possible for any token.

First, producers infrequently accepted a plain token when *they knew* it was the only type available (0.26 freq.) and simply defected (0.60). Compare this with a 0.59 frequency of *Sell* under an identical decisional situation in FIAT (Table 5). Second, when consumers had just sophisticated tokens (19% of meetings) they preferred to keep them (0.67 freq.) even if producers demanded them (0.69 freq.). Third, when consumers were known to have both types of tokens (32% of meetings), producers shunned the plain and demanded the other (0.10 vs. 0.60). Consumers did the opposite, offering the plain while hoarding the other (0.58 vs. 0.23). This incompatibility of choices persisted.

Hoarding sophisticated tokens, while offering plain tokens as a consumer and refusing them as a producer prevented the circulation of both kinds of tokens. This precluded the emergence of monetary trade convention, leading to low cooperation and efficiency. By contrast, we do not see this in FIAT2, where trading choices' were similar to FIAT economies (89% vs. 86% for *Spend*, and 53% vs. 59% for *Sell*, see Table 5). We thus exclude that the minimal plain tokens trade in MIX is due to the mere doubling of the number of tokens.

Table 10: Outcomes in a FIAT2 and MIX meeting: Marginal Effects.

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

Notes: Multinomial logit regression on outcome experienced by producers in a meeting. One obs.=one producer in rounds 1-16 (all meetings). Data from Fiat (the base of the regression), Fiat2, and Mix ($N = 6114$). Dep. Variables: *D*= producer selects D, *Failed Trade*=producer selects Sell for some token but the consumer’s choice is incompatible, *Gift*= producer selects C, and *Monetary Trade*=producer selects Sell for some token and the consumer offers that token. 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 round 1-16, and standard controls (not reported). Symbols * * *, **, and * indicate significance at the 1%, 5% and 10% level, respectively.

The multinomial logit regression in Table 10 establishes the significance of these observations. The dependent variable is a categorical variable taking one of four possible values based on four mutually exclusive outcomes that can be experienced by a producer: (i) “D” if no cooperation occurs because the producer refuses to cooperate (selects D); (ii) “Failed Trade” if no cooperation occurs because the producer’s choice to trade for a specific token is incompatible with the consumer’s; (iii) “Gift” if cooperation occurs because the producer unconditionally cooperates (selects C); and (iv) “Monetary Trade” if cooperation occurs because the producer and consumer’s choices to trade cooperation for a specific token are compatible. Two indicator variables capture treatment effects (FIAT is the base), and the additional explanatory variables used in the earlier logit regressions are included.

Doubling the supply of plain tokens did not significantly affect the distribution of outcomes (the coefficients on FIAT2 are close to zero and insignificant).

Yet, we cannot reject the hypothesis that adding sophisticated tokens to plain tokens affected outcomes: monetary trade declined by 30 percentage points, due an increase in failed trades (the coefficient on *Mix* is negative and highly significant in cols. 2 and 4). There is no significant effect on the frequency of gifts or unconditional defection (the coefficient on *Mix* is small and insignificant in cols. 1 and 3). Hence, H3 can be rejected for MIX. Possibly, the option to choose between different tokens acted as a friction, increasing coordination complexity that prevented the development of a monetary trade convention. To investigate this, we ran the SWITCH treatment.

5.4 Engineering a transition to sophisticated tokens

The SWITCH treatment alters the FIAT design by replacing plain with benefit-yielding tokens after supergame 2. If coordination complexity is responsible for the lack of monetary trade in MIX, then having a chance to initially develop a monetary trade convention with plain tokens should facilitate a transition to benefit-yielding tokens. To mitigate hoarding, benefit-yielding tokens yield either 0 or 2 points with equal probability (iid across rounds), so the expected benefit is 1 point as in REWARD, but less attractive being random. We thus can compare SWITCH to FIAT in supergames 1-2, and to REWARD in supergames 3-5. Based on the data, we can reject H 4.

Result 8. *In SWITCH, monetary trade and cooperation permanently declined after benefit-yielding tokens replaced plain ones. Monetary trade was less frequent than Fiat but more frequent than Reward.*

Fig. 3 shows that switching to benefit-yielding tokens stunted the development of a monetary system, as players less frequently traded tokens for cooperation. Cooperation in SWITCH and FIAT is similar in supergames 1-2

(0.46 vs. 0.48 on average). In supergames 3-5 it falls toward REWARD levels (0.35 vs. 0.26), a decline due to a drop in monetary trade. Before supergame 3, monetary trade is slightly more frequent in SWITCH than FIAT (0.31 vs. 0.26); afterward, it declines to 0.27, which pushed the economy close to but not as low as REWARD levels (0.15 on average in supergames 3-5). This suggests that initially establishing a monetary trade convention with plain tokens helped to support the exchange of sophisticated tokens—to some extent. As in REWARD, the cause of this decline is hoarding behavior. In supergames 3-5, consumers who had a token offered it in 76% of meetings as compared to 92% of FIAT. These observations are significant according to a panel regression in Supp. Mat., Table B7. Hence, we can reject H3-H4 when benefit-yielding tokens replaced plain ones. The coordination on trade achieved with plain tokens suffered as sophisticated-tokens replaced them.¹⁷

6 Discussion

Central Bank digital currency 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. Standard theory does not raise specific concerns about the interest-bearing feature 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

¹⁷This 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.

monetary system did not emerge, or was poorly functioning, efficiency also suffered because participants were unable to support high-payoff equilibria without a well-functioning monetary system. This evidence confirms the findings about the nature of money earlier reported in Camera and Casari (2014) and related studies. Exchanging an intrinsically worthless tokens supported cooperation because in the experiment there are multiple equilibria and players' incentives are imperfectly aligned. Trading a token for cooperation mitigates strategic uncertainty problems, facilitating coordination on efficient play. This coordination role of monetary exchange is especially valuable as groups grow in size (Camera et al., 2013), and operates also if reputation mechanisms are available (Bigoni et al., 2020). Among its benefits, monetary trade makes cooperation evolutionarily stable because it boosts traders' fitness above that of free riders (Camera et al., 2013), and is risk dominant because it limits exposure to potential losses, unlike non-monetary norms of cooperation (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 benefit when meeting unconditional cooperators; (iii) it limits off-equilibrium economic losses to meetings where consumers have no tokens (no trade is possible), thus making cooperation more resilient to isolated misconduct as compared to a trigger strategy based on coordinated community punishments.

In economies exclusively endowed with plain tokens, participants learned to optimally reallocate resources among themselves through monetary exchange (Result 2). This contrasts with economies exclusively endowed with sophisticated, interest-bearing tokens, which failed to develop a monetary system (Results 3-5). This is a novel result, which offers a fresh perspective for Central

Banks considering currency innovation. One may conjecture that penalizing currency holdings should discourage hoarding and boost spending; conversely, rewarding holdings should increase the instrument's attractiveness, encourage its acceptability, hence its circulation and value.¹⁸ 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.

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

¹⁸For instance, Coeuré 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.”

refuse tokens that generate penalties (as the token might not be expendable).

These findings emerge also when participants had a choice of tokens (Results 6-7). This is surprising because in MIX plain tokens could support trade as in a Gresham's Law equilibrium where the "bad" money circulates and the "good" money is hoarded. But MIX stunted the emergence of a monetary system—benefit-yielding tokens were hoarded while plain tokens were seldom accepted. Possibly, having two types of tokens magnified coordination problems.¹⁹ Yet, other factors must be at play because monetary trade declined also in SWITCH when interest-paying tokens replaced plain ones—though trade did not completely unravel as it happened in REWARD (Result 8). Hence, the coordination achieved with plain tokens did not entirely dissipate.

Would the results change in a design where monetary trade is imposed and gift-giving is ruled out? Two earlier experiments suggest a reason for skepticism. In Camera et al. (2003) buyers and sellers traded on a market with a plain fiat money or an interest-bearing money. Fiat money supported high efficiency, but not the interest-bearing money—which induced hoarding. In Camera et al. (2016) random buyer-seller pairs traded either with a plain cash instrument or a superior electronic payment instrument that was costly to sellers. Sellers largely accepted electronic payments but not buyers, which prevented their widespread adoption and lowered efficiency. This evidence suggests that adoption of a new payment instrument may fail even if sellers accept it—both sides of the market must be receptive to the innovation.

¹⁹This result would likely hold even if failed trades could be re-attempted with another token. Counterparts' choices were observable, so participants could coordinate over time. Yet, the mismatch in offers and requests persisted: producers kept demanding interest-paying tokens, while consumers insisted on offering plain ones. The cash and digital payments instruments experiment in Camera et al. (2016) also reveals that allowing buyers to offer a payment instrument and switch to another upon the seller's refusal, did not fundamentally alter results about adoption, pricing, and efficiency as compared to a baseline scenario where failed trades could not be reattempted.

The angle of inquiry of this study can help evaluating different typologies of currency innovation, and assess the design of digital currencies. An insight is that absent externally-imposed transaction catalysts, e.g., legal tender or full convertibility, introducing a new currency instrument may backfire if it engenders strategic uncertainty, mistrust or miscoordination. To the extent that the principles of operation in the experiment also apply to field economies, it sheds light on possible shortcomings of introducing a novel currency instrument. Are there preventive steps to avoid possible monetary system instability? Legal tender laws could help mitigate acceptability problems, albeit without entirely eliminating them. A transparent and trusted regulatory framework that imposes clear limits on size and scope of possible benefits or penalties on the instrument might address hoarding tendencies and reduce adoption problems. Overall, this study uncovered a desirable feature of currency instruments: they should be plain, and hence unencumbered by additional valuation margins inherent in more sophisticated instruments. In the experiment, those additional valuation aspects distorted decisions, preventing a focus on the instrument's primary role, which is to serve as a trusted means of payment.

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A Appendix

A.1 Design and Procedures: Additional Details

Sophisticated Tokens: several reasons suggest a design where interest is paid in points, and not tokens. First, we wish to maintain a stable supply of tokens, which in the baseline treatment is fixed at four. Paying interest in token would not allow a stable token supply in sophisticated-token treatments. Second, a varying token supply would bias the outcome against monetary trade; a growing or declining token supply distorts economic incentives during the supergame (altering the value of holding a token) and adds unnecessary complexity to the cognitive task faced by subjects.

Interaction in a meeting of the Mix treatment. This section discusses the actions available in a meeting of MIX, when two token types (called A and B) are held by the consumer. The stage game is in Table A1.

Table A1: The stage game when the consumer has two token types, A and B

		Producer			
		D	C	Sell for A	Sell for B
Consumer	Idle	3, 6	15, 0	3, 6	3, 6
	Spend A	3, 6	^(A) 15, 0	^(A) 15, 0	3, 6
	Spend B	3, 6	^(B) 15, 0	3, 6	^(B) 15, 0

Notes: Payoffs to Consumer, Producer, in points. ^(A) and ^(B) indicate the transfer of a token of type A and B from consumer to producer. The table depicts the game when the consumer has both kinds of token(s), at least one each. If the consumer has only one type of token, Table 2 applies. 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. Plain tokens were called “white tickets” while interest-bearing tokens were called “yellow tickets” (see Instructions in Appendix B).

The grey area depicts the game if no tokens are held by the consumer.

Hence, unconditional cooperation and unconditional defection are choices that are always available to a producer. If the consumer has just one token type (either A or B), then the stage game is as in Table 2. Table A1 is the natural extension when the consumer has two token types (A and B). The same direct mechanism used in the FIAT treatment is retained here.

At the start of a meeting, counterparts see the type of tokens in the counterpart's possession (not the quantity, to ensure anonymity). Then, both counterparts make simultaneous choices without any prior communication, selecting if and what kind of token to accept (producer) or offer (consumer). To minimize the cognitive load, producers are *not* given the option to sell for a given token if the consumer *does not* have that specific token. Furthermore, two tokens cannot be offered at the same time, or one after the other. Hence, counterparts do not have the option to attempt another trade if one fails, and find an agreement within that same meeting (for an experiment with this possibility, see Camera et al., 2016). If the choices are compatible with monetary exchange, then the token is transferred and cooperation occurs. Otherwise, the default outcome is no transfer of token and no cooperation. As an example, if a producer asks for token A from a consumer who has A and B tokens, and the consumer offers token B, then the outcome is defection and no token transfer. At the end of the meeting, players see the outcome, are reminded of their own action, and are informed of the counterpart's action; this facilitates coordination on a mutually compatible strategy as players can understand the reason for a failed token exchange, and can see what token (if any) was selected by the counterpart. Results from previous periods in the supergame are always visible at the bottom of the screen.

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 cooperate 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 \mathbf{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 A2.

Table A2: 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. 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, defecting in t gives payoff $u + d - l$ (instead of $u + g$) to the deviant consumer; she enters $t + 1$ as a producer *with* money and reverts back to following monetary trade. The round after deviating, she is a producer with a token; hence, she chooses D, as specified by the monetary strategy. In the best-case scenario, in $t + 1$ the deviator meets the person who suffered from her initial defection. If so, 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

Profits are 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.²⁰ Given role alternation, profit is (approximately) the average payoff in two consecutive rounds:

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

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.

A.4 A measure of liquidity value of tokens

This section calculates a rough measure of the liquidity value of tokens in three treatments, FIAT, PENALTY and REWARD.²¹ This liquidity value is an

²⁰Let $c_t = 1$ 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.

²¹I thank an anonymous reviewer for suggesting this additional analysis.

indirect flow payoff, the difference between the income expected by a consumer entering a meeting with some tokens as opposed to none. Consider Table 8. To calculate the value of liquidity, consider the value of having *some* token in the next round (1 or more) as compared to none (for a current producer). Let p_{ij} denote the probability of meeting a producer with $j = 0, 1+$ tokens, conditional on being a consumer with $i = 0, 1+$ tokens. So, $p_{i0} + p_{i1} = 1$, which can be calculated from Table 8. Let c_{ij} denote the probability of cooperation in that meeting (the number in parentheses in the Table).

The expected value to a producer, from entering the next round with 0 or some tokens can be calculated as follows:

$$v_i = 3 + (p_{i0}c_{i0} + p_{i1}c_{i1}) \times 12, \quad i = 0, 1+.$$

Here 3 refers to the points a consumer earns for sure, and 12 are the extra points earned if the producer cooperates. This cooperation is uncertain due to uncertainty in strategy selected by the various counterparts. Recall also that holding a token might generate direct flow payoffs, but these are not included in the liquidity value of the token.

The liquidity value of tokens can be broadly defined as the difference between having 0 or 1+ tokens. That is the (indirect) flow payoff $v_{1+} - v_0$ in this simplified calculation. Using the relative frequencies and cooperation rates in Table 8. we obtain the following expected values, by treatment:

Table A3: Liquidity value of tokens.

Treatment	v_0	v_{1+}	Liquidity value
Penalty	6.24	7.84	1.6
Fiat	6.97	11.04	4.07
Reward	5.23	7.24	2.01

In all three treatments the liquidity value of tokens is positive, as we should have expected given that tokens are accepted by some players in all treatments. Interestingly the liquidity value of tokens doubles when $u = 0$ as compared to $u = -1, 1$ where monetary trade was infrequent. This rough calculation qualifies the conclusion that tokens without direct flow payoffs (i.e., no interest payments) are best-suited to support monetary exchange because they have the largest liquidity value in the experiment.