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Gabriele Camera
Marco Casari

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Gabriele Camera and Marco Casari

Purdue University University of Bologna

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Abstract

Under what conditions can cooperation be sustained in a network of strangers? Here we study the role of institutions and uncover a new behavioral foundation for the use of monetary systems. In an experiment, anonymous subjects could cooperate or defect in bilateral random encounters. This sequence of encounters was indefinite; hence multiple equilibria were possible, including full intertemporal cooperation supported by a social norm based on community punishment of defectors. We report that such social norm did not emerge. Instead, the availability of intrinsically worthless tokens favored the coordination on intertemporal cooperation in ways that networks of strangers were unable to achieve through social norms.

Keywords: money, cooperation, information, trust, folk theorem, repeated games
JEL codes: C90, C70, D80

1. Introduction

Impersonal exchange is a fundamental trait of developed market economies (Granovetter, 1985; North, 1990; Seabright, 2004). Its main feature is that it expands the set of trade opportunities because it does not require high levels of information about others' past behavior, unlike personal exchange. Consequently, if trade frictions hinder impersonal exchange, then opportunities for mutual gain may be lost.[1] In developed economies, impersonal exchange is

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* Correspondence address: G. Camera, Dept. of Economics, 425 W. State St., Purdue University, West Lafayette, IN 47907-2056. M. Casari (marco.casari@unibo.it), University of Bologna, Department of Economics, Piazza Scaravilli 2, 40126 Bologna (Italy), voice: +39 051 209 8662, fax: +39 051 209 8493. We acknowledge research support from the following grants: Einaudi Institute for Economics and Finance and NSF grant.no. DMS-0437210. Earlier versions of this paper were circulated under the title "Institutions for long-run cooperation: experiments on markets with frictions." We thank seminar participants at National Taiwan U., National Seoul U., City U. of Hong Kong, Cattolica U., Simon Fraser U., ESA 2009 and 2010 meetings, LabSi workshop 2010, Collegio Carlo Alberto, and the Universities of Illinois, Bologna, Salerno, Napoli "Federico II," Napoli 2, Pittsburgh, and Texas-Austin. We also thank Nianqing Liu, Tong Le, and especially Maria Bigoni for outstanding research assistance.

[1] For example, this is a key feature of "frictional" macroeconomic models, which include explicit obstacles to the realization of mutually beneficial exchanges, such as lack of information about identities and past behaviors of

facilitated by state enforcement, fiat money, and other institutions because of social distance, the possibility to break promises and anonymity in interactions.

This paper is an experimental study about institutions designed to facilitate impersonal exchange, in particular it studies fiat money. Monetary exchange is a defining feature of virtually every economy. Yet, money plays no role in most economic models: the basic insights from theories of growth, business cycles, asset pricing, or unemployment for instance, emerge from models where money is not an essential element. So, what is the role of money? In the monetary theory literature, money emerges *only* to expand the efficiency frontier. Put simply, money enables transactions that would not otherwise occur through impersonal exchange (see the survey in Ostroy and Starr, 1990). What the literature has overlooked, and this study has uncovered, is a role of money as a tool for equilibrium selection in the intertemporal giving and receiving of goods. This may well be the behavioral foundation for the use of money.

We model impersonal exchange by introducing a novel design that makes transparent the intertemporal dimension of cooperation in a network of strangers. An economy comprises a stable population of four anonymous subjects who interact in pairs with changing opponents. Building a reputation is impossible by design because subjects remain anonymous, i.e. they cannot observe the opponent's identity and they are randomly rematched after each encounter. In every encounter one subject has a good and can consume it (defect or autarky), or transfer it to her opponent who values it more (cooperate). Social efficiency requires that everyone with a good transfers it to others. In this framework there is no possibility for direct reciprocation, yet subjects could sustain the efficient outcome through a social norm of cooperation based on community enforcement of defections. This was possible because the interaction had a long-run horizon, implemented through a random stopping rule (e.g., as in Palfrey and Rosenthal, 1994, Dal Bó and Fréchette, forthcoming).

Indefinite repetition of the game induces multiple equilibria ranging from full defection to the efficient outcome. According to Folk Theorem-type results, self-regarding individuals can overcome the temptation of short-run gains and attain the efficient outcome by threatening permanent autarky through a decentralized punishment scheme that spreads by contagion (Kandori, 1992, Ellison, 1994). The theoretical literature often implicitly assumes that agents coordinate on the best equilibrium available. In this case, institutions are useful only if they help

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others, difficulties in coordinating trade, or limitations in enforcement and punishment. E.g., see Diamond (1982).

to expand the efficiency frontier, but are useless if efficiency can be achieved through decentralized enforcement (e.g., Milgrom et al., 1990). In our experimental economies any institution, including money, is theoretically unnecessary to reach efficiency.

By experimentally controlling the informational flows and the matching process, our laboratory economies capture trade frictions typically observed in larger economies without the need to let hundreds of people interact together. Our design precludes relational contracts and direct reciprocity and so removes strong and empirically relevant motivational forces for cooperation in society (Henrich et al, 2004, Nowak, 2006). Even if efficiency is within theoretical reach, achieving it in practice is especially difficult when individual reputations are absent (Ostrom, 2010). Moreover, the experimental evidence from indefinitely repeated prisoners' dilemmas has documented that overcoming the complexities of community enforcement is difficult even in small groups (Camera and Casari, 2009). Adopting an individual decision problem as a stage game—as opposed to a strategic game—sets this study apart from previous cooperation experiments based on indefinitely repeated prisoner's dilemmas and other social dilemmas (e.g., Engle-Warnick and Slonim, 2006). In our framework, achieving cooperation amounts to engaging in an inter-temporal giving and receiving of anonymous gifts.

To experimentally study fiat money, in a treatment subjects could hold and exchange worthless electronic objects. This neither removes any equilibria of the baseline treatment nor adds Pareto-superior equilibria. Monetary exchange emerged as a powerful tool for equilibrium selection. When tickets were available, subjects changed strategies and patterns of cooperation. Monetary exchange behaviorally facilitated coordination on the efficient outcome and redistributed surplus from frequent defectors to frequent cooperators. In the experiment, the adoption of monetary exchange supported stable and predictable aggregate behavior. Participants trusted that cooperation would be reciprocated through the exchange of intrinsically worthless tokens. The mechanism behind this is that with a monetary system in place defection does not trigger a switch to uncooperative behavior. This experimental evidence shows that the value of monetary exchange goes beyond expanding the efficiency frontier.

Additional treatments investigated the role of money as carrier of information about individual past behavior. It has been argued that money simply fills a record-keeping need when the past history of other participants is unknown (e.g., Ostroy and Starr, 1990, Kocherlakota, 1998); in our experiment holding money is statistical evidence of past cooperative behavior. We empirically compare money with institutions that develop individual public records and resemble a Better Business Bureau or a Credit Bureau. We report weak evidence in favor of a purely record-keeping role of money and conclude that the role of monetary exchange goes beyond bridging informational gaps.

These findings offer new insights about a fundamental question in game theory: under what conditions can cooperation be sustained in a network of strangers engaging in anonymous, long-term interactions? (e.g., Binmore, 2005). The existing evidence is largely limited to two-person economies (e.g., Dal Bó and Fréchette, forthcoming). In addition, the study contributes to a theoretical literature on institutions designed to sustain intertemporal trade under limited commitment (e.g., Krasa and Villamil, 2000), and a large theoretical literature that has adopted repeated games or random matching economies as a platform for micro- and macro-economic analysis. For example, consider models of unemployment (Diamond, 1982), of economic governance (Dixit, 20003), of the organization of commerce (Milgrom, et al. 1990), and of money (Kiyotaki and Wright, 1989), Experiments with anonymous economies provide much needed empirical evidence to assess the validity of such theories. This study contributes also to an experimental literature on money. In previous experiments, either money has redemption value (e.g., Lian and Plott 1988), or money must be used to expand the efficiency frontier (e.g., Duffy and Ochs, 2002), or subjects interact for a fixed number of periods (e.g., McCabe, 1989, Camera et al. 2003). In contrast, money in our design has neither intrinsic nor redemption value, the efficient allocation is an equilibrium even without money, and subjects interact indefinitely.

The paper proceeds as follow. Section 1 presents the experimental design. Section 2 includes the theoretical predictions. Sections 3 and 4 illustrate the results. Section 5 concludes.

2. Experimental design

This section describes the *Baseline* and the *Tickets* treatment. As illustrated in Table 1, the experiment has overall four treatments; the two remaining treatments are described in Section 4. In all treatment the interaction was anonymous and local. The interaction was local because subjects observe only the outcome in their pair, not in the rest of the economy.

The stage game in the Baseline treatment. Consider the following individual decision problem, or gift-giving game: there is a seller who can consume a good in her possession or transfer it to a buyer who values it more than the seller. The seller (called “Red” in the experiment) chooses one of two actions: outcome Y (a choice called *defection* or *autarky*) and outcome Z (a choice called *cooperation*). The buyer (called "Blue" in the experiment) has no action to take. The payoffs for seller and buyer are, respectively, (a, a) if Y occurs and (d, u) if Z occurs. Here $a>0$ is the autarky payoff, while $d \in (0, a)$ and $u > 2a - d$ are payoffs under cooperation. In the experiment $d=2$, $a=8$, $u=20$. The dominant strategy for the seller is autarky, Y. Total surplus is maximum when the seller cooperates, i.e., Z is the outcome.

The supergame. We consider economies composed of four players who interact for an indefinite number of periods. In each period players first randomly meet an opponent and then are randomly assigned a role, either seller or buyer, to play the gift-giving game described above (shaded area in Table 2). This interaction describes a situation where strangers can engage in an inter-temporal giving and receiving of goods.

A supergame or *cycle* consists of an indefinite interaction among subjects achieved by a random continuation rule, as in Roth and Murnigham (1978). A supergame that has reached a period continues into the next with a probability $\delta = 0.93$ so the interaction is with probability one of finite but uncertain duration. We interpret the continuation probability δ as the discount factor of a risk-neutral subject. The expected duration of a supergame is $1/(1-\delta)$ periods, so in each period the supergame is expected to go on for 13.28 additional periods. In our experiment the computer drew a random integer between 1 and 100, using a uniform distribution, and the supergame terminated with a draw of 94 or of a higher number. All session participants observed the same number, and so it could have also served as a public randomization device.

Total surplus in the economy is maximized when everyone cooperates, i.e., when all sellers always choose Z. In this case, the surplus in a pair is 6 points (22 minus 16), and in an economy it is 12 points. We refer to this outcome as the *efficient* or fully cooperative outcome. If all sellers in the economy always select Y, then we say that the outcome is *permanent autarky*.

*The experimental session***.** Each experimental session involved twenty subjects and five cycles. We built twenty-five economies in each session by creating five groups of four subjects in each of the five cycles. This matching protocol across supergames was applied in a predetermined fashion. In each cycle each economy included only subjects who had neither been part of the same economy in previous cycles nor were part of the same economy in future cycles. For the entire cycle a subject interacted exclusively with the members of her economy. Subjects were informed that no two participants ever interacted together for more than one cycle, though were not told how groups were created. Adding other cycles beyond five, would have introduced the possibility of contagion across economies because some participants would have interacted together for multiple cycles. Cycles terminated simultaneously for all economies.

Participants in an economy interacted in random pairs according to the following matching protocol within a cycle.[2] At the beginning of each period, the economy was randomly divided into two pairs of participants, i.e., each subject randomly met one opponent (called "match" in the experiment). There are three ways to pair four participants in an economy. In each period one pairing was randomly chosen with equal probability, so a subject had one third probability of meeting anyone else from their economy in each period of a cycle. Once pairs were formed, in each pair a computer-determined coin flip assigned to one player a seller role (red) and a buyer role to the other (blue). This random assignment implied that subjects could change role from period to period and in each period every economy had two buyers and two sellers.[3]

TABLE 1

Tickets treatment. In each economy there was a constant supply of four tickets. We call "ticket" an electronic object that is intrinsically worthless because holding it yielded no extra points or dollars, and it could not be redeemed for points or dollars at the end of any cycle. In period 1 of each cycle, each buyer was endowed with two tickets. Tickets could be carried over to the next period but not to the next cycle.

Tickets could be transferred from buyer to seller, one at a time, and subjects could hold at most two tickets. As illustrated in Table 1, a buyer could either keep the tickets (action 0), unconditionally transfer one ticket to the seller (action 1), or transfer one conditional on the outcome being Z (action $1|Z$); hence, the action set of the buyer is $\{0,1,1|Z\}$. The seller could either choose to execute outcome Y, execute outcome Z, or execute outcome Z conditional on receiving one ticket from the buyer (action $Z|1$). Hence, the action set of the seller is $\{Y,Z,Z|1\}$. These choices were made simultaneously, without prior communication and were private information, i.e., only the outcome could be observed but not the opponent's choice. If the choices were incompatible, then the outcome was Y (Table 2). Because only the outcome was

[2] For comparison purposes, a "partner" treatment differs from our treatments in the matching protocol (fixed pairings instead of random), may differ in anonymity (subject IDs may be observable), and is otherwise informationally identical to our *Baseline* treatment.

[3] The random role assignment helps to implement impersonal interaction as it restricts knowledge of the opponent's history as opposed to random matching with fixed roles or deterministic alternation in roles. The latter design behaviorally favors coordination on cooperation.

observed, not the action, subjects could not signal their desire to cooperate by requesting or offering a ticket.[4]

As seen above, the strategy sets include conditional and unconditional actions. The seller can choose to implement outcome *Z* conditional upon receiving a ticket. The buyer can choose to transfer one ticket conditional upon *Z* being implemented. If subjects attach value to tickets, then conditional actions facilitate coordination on the outcome where there is cooperation in exchange for one ticket. This outcome can also be achieved through other actions, in particular choosing *Z* and choosing to transfer a ticket unconditionally. The typical monetary model assumes that exchange is *quid-pro-quo*: buyer and seller make simultaneous proposals and only compatible proposals are implemented. Incompatible proposals lead to autarky. This requires the availability of conditional actions. Our design captures this key theoretical aspect without favoring the emergence of monetary exchange. The design ensures subjects can neither incur involuntary losses, nor can garnish their opponent's endowment or earnings. With conditional strategies, a seller is "compensated" with one intrinsically worthless ticket for implementing *Z* if and only if the buyer is compensated for her ticket with a cooperative outcome. Non-compliant opponents are immediately sanctioned with autarky: cooperation is withheld from buyers who do not transfer a ticket and no ticket is given to sellers who choose *Y*.

For tractability reasons, some constraints on ticket transfers had to be imposed. Subjects could not borrow (short sell) tickets—a standard assumption in monetary models. No subject could hold more than two tickets to avoid having someone accumulating all tickets. Because each subject could hold 0, 1, or 2 tickets, ticket transfers cannot take place in every circumstance. A ticket transfer is *feasible* when the buyer has 1 or 2 tickets and the seller has 0 or 1 tickets. A transfer is *unfeasible* either when the buyer has 0 tickets or when the seller has 2 tickets. Consequently, buyer or seller may have a restricted choice set when a ticket transfer is unfeasible. In the experiment, a buyer with 0 tickets had no action to take, while a seller with 2 tickets could only choose to execute outcome *Y* or *Z*. Before making a choice, subjects received some information about the opponent's ticket holdings. The seller was told whether the buyer

[4] In a pilot session run on April 17, 2007, buyers had four options available, including two conditional strategies: offer 1 ticket in exchange for Y and offer 1 ticket in exchange for Z. Buyers overwhelmingly chose the latter strategy (the relative frequency is 17 times greater). Given this evidence, not all possible conditional choices were included in the design either because they are theoretically redundant (e.g., offer *Y* in exchange for 0 tickets, or offer 0 tickets, in exchange for *Y*), or to minimize subjects' confusion (e.g., offer *Z* in exchange for 0 tickets, or offer a ticket in exchange for *Y*).

had either 0 or some tickets; the buyer saw whether the seller had either 2 or less than 2 tickets. Hence, subjects were informed whether tickets exchange was feasible in their match, in a manner that minimized the chance that such information would indirectly reveal identities. Table 2 reports all possible outcomes for the *Tickets* treatment, when ticket transfers are feasible and not.

Introducing less than four tickets would have increased the fraction of unfeasible matches, while introducing more than four would have reduced the endogenous value of tickets. Fixing a two-unit upper bound for ticket holdings simplifies the subject's task to formulate a prediction on the distribution of ticket holdings. Removing this bound does not change the fraction of unfeasible matches in monetary equilibrium because the *endogenous* bound on ticket holdings is 2 (see Section 3). In addition, removing the two-unit bound cannot increase the fraction of feasible matches relative to our setup.[5]

TABLE 2

Considering all four treatments, we recruited 160 subjects through announcements in undergraduate classes, half at Purdue University and half at the University of Iowa. The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007). Instructions (a copy is in the Appendix) were read aloud at the start of the experiment and left on the subjects' desks. No eye contact was possible among subjects. Average earnings were $17.60 per subject. On average, a session lasted 73.5 periods for a running time of 2 hours, including instruction reading and a quiz.[6] Details about the number and length of sessions are provided in Table 1 (each session had 20 participants and 5 cycles).

3. Theoretical predictions

In the one-shot gift-giving game the dominant strategy for the seller is autarky, *Y*. This outcome is inefficient; the expected payoff of each player is maximized when Z is implemented. Indefinite repetition of the game with random opponents expands the equilibrium set. A main goal of this section is to prove that in all treatments the equilibrium set includes 100% cooperation, which is the efficient outcome. The analysis is based on the works in Kandori

[5] Intuitively, if one subject holds all four tickets, then at least one buyer has no tickets. If one subject holds three tickets, then there is only one ticket for all other subjects. To verify the empirical validity of this prediction, we run a follow-up session run on Feb 4th, 2010 where we removed the upper bound on ticket holdings. The fraction of feasible matches did not increase (67.6%, cycles 1-2, vs. 67.3% in this experiment) because only 6.4% of the subjects chose to hold more than two tickets.

[6] Subjects were recruited for three hours in order to ensure that, given the random termination protocol, the time constraint would not be binding.

(1992) and Ellison (1994), under the assumption of identical players, who are self-regarding and risk-neutral. The payoff in the repeated game is the (ex-ante) expected discounted stream of payoffs in the one-shot games.

Consider the *Baseline* treatment. It is characterized by two informational frictions. Players can only observe the outcome in their pair (private monitoring). They can neither observe identities of opponents (anonymity), nor communicate with them, nor observe action histories of others. The worse outcome is a sequential equilibrium under the strategy "defect forever." Clearly, Y is a best response to all sellers playing Y in all periods. In this case the payoff in the repeated game is the value of autarky forever, $a/(1-\delta)$.

If δ is sufficiently high, then the efficient outcome can also be sustained as a sequential equilibrium. To prove it, conjecture that players behave according to actions prescribed by a social norm, which is a rule of behavior that identifies "desirable" play and a sanction to be triggered if a departure from the desirable action is observed. For a seller, we identify the desirable action with Z and the sanction with Y, hence we define the following strategy.

Definition 1 (grim trigger strategy). *As a seller, the player cooperates as long as she has never experienced an outcome Y, and otherwise defects forever after whenever she is a seller.*

According to this strategy, deviations are policed in a decentralized manner. Anyone who experiences outcome Y (as a buyer or a seller) triggers a contagious process of defection as soon as she is a seller, which eventually leads to permanent autarky. We have the following result.

Proposition 1. *In the indefinitely repeated gift-giving game there exists a non-trivial interval* $(\delta_L,\delta_H)\subset[0,1]$ *for the discount factor, such that if* $\delta\in(\delta_L,\delta_H)$*, then the grim trigger strategy supports the efficient outcome as a sequential equilibrium.*

The proof, in the Appendix, is based on the extension of the Folk Theorem in repeated games to random matching environments (Kandori 1992, Ellison 1994). Here, we provide intuition. Remember that in each period payoffs for (seller, buyer) are (u, d), if cooperation is the outcome, and (a, a), if autarky is the outcome. If everyone adopts the grim trigger strategy, then on the equilibrium path every seller cooperates so everyone's payoff is the expected discounted utility from buying or selling with equal probability, $(u+d)/[2(1-\delta)]$. However, a seller might be tempted to defect to earn $a>d$. Since $a<(u+d)/2$ is assumed, the threat of autarky forever can remove such a temptation. A seller deviates in several instances: in equilibrium, if she has not observed play of *Y* in the past but chooses *Y* currently, i.e., she "cheats," and second, off-equilibrium, if she has observed play of *Y* in the past but chooses *Z* currently, i.e., she does not punish as she should.

Consider one-time deviations by a single seller. Cooperating when no defection has been observed is optimal only if the agent is sufficiently patient. The future reward from cooperating today must be greater than the extra utility generated by defecting today (unimprovability criterion). Instead, if autarky occurs and everyone plays grim trigger, then everyone eventually ends up in autarky since the initial defection will spread by contagion. Contagion to 100% autarky in our experimental economies occurs quickly because there are only four players.

Cooperating after observing autarky should also be suboptimal. Choosing *Z* can delay the contagion, but cannot stop it. To see why, suppose a player observes *Y*. If the next period he is a seller and chooses *Z*, then this yields an immediate loss because he earns *d* instead of *a*. Hence, the player must be sufficiently impatient to prefer playing *Y* than *Z*. The incentive to play *Y* increases in *a* and decreases in *d*. Our parameterization ensures this incentive exists for all $\delta \in (0,1)$ so it is optimal to play *Y* after observing (or selecting) *Y*. For the efficient outcome to be an equilibrium, we need $\delta > \delta_L = 0.808$ and $\delta < \delta_H = 1$. In our experimental design $\delta = 0.93$.

Proposition 2. *In the Baseline treatment the equilibrium set includes permanent autarky and the efficient outcome. In the Tickets treatment, the addition of tokens does not eliminate any equilibria of the Baseline treatment.*

To prove the first part of the statement, simply note that, due to indefinite repetition, if all subjects adopt the grim trigger strategy, then the efficient outcome can be sustained as a sequential equilibrium.[7] Permanent autarky is also an equilibrium because autarky is always a best response to play of autarky by the opponents. The second part of the statement immediately follows because intrinsically useless tokens can always be ignored. Put differently, all strategies available in the *Baseline* treatment are available in the *Tickets* treatment. Hence, the *Tickets*

[7] T-periods punishment strategies, which are feasible in experiments among partners, cannot support the efficient outcome as an equilibrium in our experiment, due to private monitoring. Suppose a pair of agents starts to punish for T periods, following a defection in the pair. Due to random encounters, this initial defection will spread at random throughout the economy. Hence, over time different agents in the economy will be at different stages of their T-periods punishment strategy, which does not allow agents to simultaneously revert to cooperation after T periods have elapsed from the initial defection.

treatment does not introduce Pareto-superior equilibria and the efficient outcome can be supported in both treatments. However, additional strategies are available in the *Tickets* treatment. The additional strategies available in the Tickets treatment do not expand the equilibrium set—the efficient outcome is already attainable—but they might actually increase coordination problems relative to the Baseline treatment, because the possibility to transfer tokens adds choices. In particular, a strategy that is the basic building block in monetary economics becomes available.

Definition 2 (fiat monetary exchange strategy). *As a seller, the player offers cooperation in exchange for an intrinsically worthless ticket. As a buyer, the player offers a ticket in exchange for cooperation.*

Definition 2 reflects the standard definition of behavior under monetary exchange. The fiat monetary exchange strategy prescribes cooperation for the seller and the transfer of one ticket for the buyer. A deviation from this strategy leads to autarky *in the period*. The modifier "fiat" emphasizes that tickets are intrinsically useless, i.e., they cannot be redeemed for points. Monetary exchange can be implemented using conditional strategies $Z|1$ for the seller and $1|Z$ for the buyer, both in and out of equilibrium. Such a strategy reflects the *quid pro quo* nature of exchange, which is a key feature in monetary theory (see the survey in Ostroy and Starr, 1990). Because exchange is conditional on a given outcome, cheating generates a loss to neither buyer nor seller; hence, issues of distrust are minimized. An alternative is to use unconditional strategies, i.e., Z for the seller and 1 for the buyer (Table 1). If subjects attribute value to intrinsically worthless tickets, then the use of unconditional strategies generates strategic risk by exposing subjects to the risk of a loss. A seller may not be compensated with a ticket for choosing Z. A buyer may not be compensated with Z for transferring a ticket.

Our design exhibits another typical feature of monetary exchange.

Definition 3 (feasibility of monetary exchange). *Monetary exchange is feasible in a match if a buyer has at least one ticket and the seller has less than two tickets.*

Not all matches admit monetary exchange because sometimes the buyer is without tickets or the seller has two tickets.[8] With random selection of seller and buyer roles, there is a strictly positive

[8] The parameterization ensured that the constraint on holding at most 2 tickets is not binding in monetary

probability that ticket transfer is unfeasible because an agent may take on the same role in more than two consecutive periods. As an example, suppose someone is a buyer in periods 1, 2, and 3, which happens with probability 1/8. The buyer starts with an endowment of two tickets; if he transfers tickets in periods 1 and 2, then he has no tickets in period 3. There exists an analogous example for a seller. Consequently, the use of the monetary exchange strategy leads to the following outcome in the period. If monetary exchange is feasible, then the outcome is *Z*, cooperation. If monetary exchange is unfeasible, then the outcome is *Y*, autarky.

The introduction of tickets expands the strategy set relative to the *Baseline* treatment. An expanded strategy set could increase coordination difficulties but it *neither constrains* subjects to employ the monetary exchange strategy, *nor precludes* the use of social norms based on decentralized community enforcement. For example, sellers could cooperate unconditionally when ticket exchange is unfeasible, and otherwise offer to cooperate only in exchange for a ticket. Given this expanded strategy set, it is meaningful to quantify the efficiency that can be theoretically achieved through monetary exchange.

Proposition 3. *In the Tickets treatment, if everyone follows the monetary exchange strategy, then the cooperation level realized is strictly below 100%. In the long-run, the economy has an efficiency loss of 42.8%.*

The proof of Proposition 3 is in the Appendix. This inefficiency result is standard in distributional models of money (e.g., Camera and Corbae, 1999). In economies with a stable population of four agents and a constant supply of four tickets there can be three possible distributions of tickets: (2,2,0,0), (2,1,1,0) and (1,1,1,1). That is to say, either two subjects have tickets (2 each), or three subjects have tickets (one has 2, and the others have 1 each), or everyone has a ticket. The fraction of matches in which ticket exchange is feasible depends on the initial distribution of tickets in a period. Moreover, the transition from a state of the economy from one period to the next depends on the random matching of subjects in pairs, the random assignment of buyer and seller roles as well as subjects' choices. The result in Proposition 3 is obtained by first calculating the unconditional (long-run) probability distribution of aggregate states, then the associated long-run fraction of matches in which monetary exchange is feasible.[9]

equilibrium. Rational sellers with 2 tickets would not choose Z in exchange for one additional ticket.

[9] Proposition 3 is not a statement about existence of monetary equilibrium. In Appendix A, we prove that monetary

Adoption of the monetary exchange strategy does not support the efficient outcome because ticket exchange is sometimes unfeasible, in which case the outcome is *Y*. In the long-run, 42.8% of matches do not admit monetary exchange. The efficiency loss measures the social cost of monetary exchange in relation to the maximum surplus, which is 12 points per economy. The *efficiency loss* is 1 minus the realized surplus over the maximum surplus.

In monetary theory, money is said to be "essential" if removing it from the economy reduces the set of possible equilibrium outcomes (Huggett and Krasa, 1996). In our design, monetary exchange is not essential. In the *Tickets* treatment, the efficient outcome can be attained using the grim trigger strategy (Proposition 2); monetary exchange sustains a Pareto-inferior outcome (Proposition 3).

To sum up, tickets cannot expand the efficiency frontier relative to the baseline treatment. In fact, their use might simply lower the efficiency frontier. However, since a multiplicity of equilibria is possible, it is an open question whether the introduction of tickets helps subjects to reach higher cooperation rates than in the *Baseline* treatment. Given that participants cannot communicate, their reputations are unknown, and personal sanctions cannot be imposed, then the selection of the efficient equilibrium and the coordination on strategies that support it is likely to be difficult, despite the indefinite time horizon (Camera and Casari, 2009).

4. Results

There are four key results: Result 1 is a benchmark for the performance in the *Tickets* treatment reported in Results 2-4. Unless otherwise noted, in the empirical analysis the unit of observation is an economy, 4 subjects interacting in a cycle. There are 50 observations per treatment.

Result 1. *In the Baseline treatment, the realized efficiency frontier (48.2%) was below the theoretical efficiency frontier.*

Tables 3-4 and Figure 1 provide support for Result 1. When averaging across all periods, the rate of cooperation was 48.2%. Only 4% of economies achieved the efficient allocation, i.e., every seller always cooperated in each period of a cycle. Only 2% of economies coordinated on

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exchange is a long-run equilibrium in our economies. Given the long-run ticket distribution associated to monetary exchange, we calculate the expected value of holding zero, one and two tickets as an unconditional expectation. A monetary equilibrium exists if, given that everyone plays a monetary exchange strategy, sellers with zero or one ticket prefer to implement cooperation, *Z*, in exchange for one ticket, instead of implementing *Y*. The key requirement is that the discount factor δ be sufficiently high; the parameters selected ensure this is the case.

autarky. Considering only period 1 of each cycle, the average cooperation rate was 51.0%; about 30% of the economies started with full cooperation and 28% with full autarky so we cannot rule out that subjects attempted to coordinate on autarky. Behavior in the baseline suggest that the representative subjects adopted a strategy articulated into a cooperative mode and a punishment mode. In particular, the representative subject who observed a defection exhibited a very strong response in the form of a long-lasting sequence of defection.[10]

Figure 1, Tables 3 and 4

What made cooperation so difficult? On the one hand, the design precludes relational contracts, direct reciprocity and reputation-building so removes strong motivational forces for cooperation (Henrich et al. 2004, Nowak, 2006, Ostrom 2010). On the other hand, cooperation is not easily sustained in practice because of the complexities of community enforcement (Camera and Casari 2009). In what follows, we thus investigate whether a monetary system has a role to play in these economies with frictions.

Result 2. *Tickets affected cooperation patterns: the realized efficiency increased when ticket exchange was feasible (61.4%) and decreased when unfeasible (12.5%).*

Tables 3-5 provide support for Result 2. In the Tickets treatment, the average cooperation rate was 46.8% overall, 61.4% when ticket exchange was feasible, and 12.5% when it was unfeasible. The difference in cooperation rates when ticket exchange was feasible or unfeasible is significant (Wilcoxon signed-rank test, p-values 0.0000, n=43; 7 economies are dropped because all matches were feasible).[11] The overall average cooperation rate of 46.8% is not significantly different from the *Baseline* treatment (Mann-Whitney test, p-values 0.78, n1=n2=50; Table 3). However, average cooperation in period 1 was 71.0%, which is significantly higher than in *Baseline* (Mann-Whitney test, p-values 0.008, n1=n2=50; Table 4).[12]

The central observation is that the efficiency frontier was no different than in the *Baseline* treatment. Yet, cooperation patterns exhibited a marked change. The data show cooperation patterns compatible with the use of the monetary exchange strategy. However, monetary exchange was not always feasible, which is a primary reason for the (in)efficiency result. Under monetary exchange, there is a theoretical prediction about the long-run distribution of ticket

[10] Supporting evidence is in Table 7.
[11] The results of the statistical tests in the paper rely on the assumption that all observations are independent.
[12] The probit regression in Table 7, col. 1 confirms this result.

holdings (Section 2). The distribution of tickets in the data is consistent with the theoretical prediction of positive mass on 0, 1 and 2 ticket holdings and symmetry between 0 and 2.[13] Sellers held 2 tickets with a frequency of 21.3%, which made them unable to accept another ticket. Buyers held 0 tickets with a frequency of 21.7%, which made them unable to offer a ticket. As a consequence, the monetary exchange strategy was not available in every encounter: on average in an economy ticket exchange was not feasible in 32.7% of matches (Table 5). Put differently, the monetary exchange strategy could sustain *at most* 67.3% cooperation.

Table 5

The next result puts forward more direct evidence that subjects employed the monetary exchange strategy.

Result 3. *Monetary exchange emerged and greatly facilitated cooperation.*

Support for Result 3 is in Tables 6, 7 and in Figures 2-3. In the experiment tickets endogenously emerged as fiat money, an intrinsically useless object valued by subjects because it facilitated the intertemporal giving and receiving of cooperation. In the Tickets treatment, there was a ticket transfer in 43.3% of matches (67.5% when considering only matches where transfers were feasible). Subjects exchanged on average 0.87 tickets per period and 1.44 when considering only period 1.[14] The data show that the transfer of tickets was instrumental to achieve cooperation, even if cooperation could be supported without ticket exchange (Proposition 2). When a ticket exchange was feasible, a ticket was transferred in 99.8% of matches with a cooperative outcome as opposed to 7.8% of matches with an autarky outcome.

As explained below, the data exhibit patterns of behavior coherent with the typical description of a monetary economy: trade was based on a quid pro quo exchange of cooperation for tickets, and tickets had a decreasing marginal value. There is overwhelming evidence that, when monetary exchange was feasible, subjects adopted *conditional* exchange strategies and

[13] In a large economy, theory predicts that the stationary distribution of ticket holdings is uniform over 0, 1, and 2. In our small economy, the distribution of tickets cannot be stationary but we can still calculate unconditional probabilities of holding 0, 1 and 2 tickets. Theoretically the probability of holding 0 tickets is about 32.1%, it is the same for 2 tickets and it is 35.7% for 1 ticket. In the data, the probability of holding 0 tickets was 31.5%, it was identical for 2 tickets, and it was 37.1% for 1 ticket. Given the *empirical* distribution of tickets (Table 5), monetary exchange is a theoretical equilibrium. The proof is in Appendix A.

[14] If all subjects followed the monetary exchange strategy and there were no issues of feasibility of ticket exchange there would be two tickets exchanged every period.

rarely used unconditional strategies (Table 6). Buyers were not willing to give a ticket unless they were sure to be compensated with cooperation. Sellers were not willing to cooperate unless they were sure to receive a ticket. This evidence suggests that subjects attributed value to intrinsically worthless tickets. A ticket was transferred *and* cooperation was the outcome in 61.2% of matches. In those matches, both subjects used conditional strategies in 83.3% of cases, while both used unconditional strategies only in 0.3% of cases.

Table 6

Adoption of the monetary exchange strategy greatly facilitated the intertemporal giving and receiving of goods in meetings where ticket exchange was feasible. Figure 2 illustrates this point by plotting the frequency of ticket exchange in a match (giving it or receiving it) versus the frequency of a cooperative outcome.[15] The two frequencies are computed at the level of individuals and exhibit a strong and positive association.[16]

Figure 2

In sum, there is evidence that tickets in the experiment became a fiat money, an intrinsically useless object valued by subjects because it facilitated the intertemporal giving and receiving of cooperation. In a way, subjects self-insured against future cooperation needs by holding tickets.

If subjects did value tickets, then why were tickets not always exchanged when feasible? A possible reason is that some subjects may have simply not employed the monetary exchange strategy. A second reason is the existence of wealth effects for those who employed the monetary exchange strategy. Following a standard result in monetary theory, wealth effects lower the incentive to cooperate for sellers who have already one ticket. If subjects attach value to tickets, then the marginal value of a second ticket is less than the first.[17] As a consequence, the incentive to cooperate is lower for sellers who already have one ticket than for those who have none. Diminishing incentives should translate into diminishing cooperation rates, which we do find in the data (Figure 3). In the experiment, sellers with 1 ticket cooperated substantially less than sellers with 0 (69.8% vs. 49.0% in feasible matches; 67.4% vs. 43.0% in all matches).

[15] These data are at the individual level and include all matches, also unfeasible ones, which explains why the frequency of ticket exchange rarely reaches 100%.
[16] A probit regression confirms a high and significant effect of ticket exchange on cooperative outcomes (Table 7, cols. 4-5).
[17] With geometric discounting, the value from the future cooperation "bought" with the second ticket is at best $\delta^2 \times 20$ as opposed to $\delta \times 20$ for the first ticket. This result is not an artifact of limiting ticket holdings to 2 (see Camera and Corbae, 1999).

Figure 3

This last consideration also allows us to discern whether *indirect* reciprocity is the primary reason behind the use of tickets. The experimental literature has identified indirect reciprocity as an important mechanism behind cooperation (e.g., Fehr and Gaechter, 2000). Tickets allow strategies based on indirect reciprocity (not direct reciprocity, given anonymity and private monitoring), which are more selective in punishment than the grim trigger strategy. A seller could cooperate only with those buyers who cooperated with others in the past and could defect with those who have defected with others in the past. Owning one or two tickets is statistical evidence of past cooperative behavior. Therefore, an indirectly reciprocal seller should cooperate when the buyer has a ticket. The evidence suggests indirect reciprocity is not what primarily drives ticket exchange. Sellers' cooperation rates should be invariant to *their* ticket holdings, but in the data sellers' cooperation rates declined in their ticket holdings (Figure 3). The data also show that sellers significantly lowered their cooperation rates when they could not acquire a third ticket, even if the buyer had one (cooperation was the outcome in 15.0% of cases if the buyer had one or two tickets and 11.7% otherwise). This is evidence of forward looking behavior and not of indirectly reciprocal, backward-looking behavior.

To sum up, the data exhibit patterns of behavior coherent with the typical description of a monetary economy: trade was based on a *quid pro quo* exchange of cooperation for tickets, and tickets had a decreasing marginal value. The next result offers a reason why monetary exchange emerged in the *Tickets* treatment.

Result 4. *Monetary exchange simplified the coordination on the inter-temporal giving and receiving of goods and redistributed surplus from frequent defectors to frequent cooperators.*

To appreciate Result 4, recall that monetary exchange does not expand the efficiency frontier; it can only lower it (Proposition 3). In the experiment, a monetary exchange strategy was adopted and though it did not empirically raise overall cooperation rates (Result 2), it did affect patterns of cooperation and improved coordination on cooperation (Result 3). We argue that these results are the consequence of two effects of monetary exchange: a simplification of coordination tasks and a redistribution of surplus from frequent defectors to frequent cooperators.

Monetary exchange promoted coordination on cooperation because it simplified off-equilibrium coordination tasks and it allowed coordination among subsets of participants in the economies. These participants trusted that cooperation would be reciprocated through the exchange of tickets. Supporting the efficient outcome through decentralized community enforcement is theoretically feasible in our four-person experimental economies but it requires a great deal of coordination. *Everyone* in the economy must coordinate both on equilibrium as well as on out-of-equilibrium play. This is so because subjects have many punishment strategies to choose from, not only grim trigger. Ticket exchange solves the off-equilibrium coordination problem because it removes entirely the need to coordinate on a punishment strategy to discourage defections. The seller who does not cooperate simply does not receive a ticket due to the *quid pro quo* nature of the monetary exchange strategy. As a consequence, subjects following a monetary exchange strategy only have to coordinate on equilibrium behavior. Moreover, they do not have to coordinate with everyone in the economy. For instance, a pair of subjects can adopt monetary exchange regardless of what others do. This is especially important in populations heterogeneous in strategies, as it is often the case in experimental economies (Camera, Casari, and Bigoni, 2010). With heterogeneity in strategies, decentralized community enforcement is likely to fail in sustaining the efficient outcome. Consider for instance an economy where everyone follows a grim trigger strategy except one subject, who starts defecting and then follows grim trigger.

The experimental literature has identified trust as an important mechanism behind cooperation (Ostrom, 2010). When individuals face incentives to behave opportunistically (as in our design), they are more likely to cooperate if trust can be increased that others will reciprocate. Monetary exchange can help to build trust by making cooperation *quid pro quo*: subjects may trust that cooperating today in exchange for a ticket will be reciprocated tomorrow in exchange for a ticket. Consistent with the above interpretation, the data show a reduction in strategic risk. Higher predictability of actions is evidence of lower strategic uncertainty, and of trust that sellers cooperate when tickets are offered.

The supporting empirical evidence is in Table 7, which reports the results from a probit regression that explains the seller's choice to cooperate (1) or not (0) overall and by treatment. The regression includes the subject’s choices only in those periods in which she is a seller. We introduce several dummy variables that control for fixed effects (cycles, periods within the cycle), for demographic characteristics such as gender and major, and for the duration of the previous cycle. A set of regressors is also included to trace the response of the representative subject when he is a seller in the periods *following* an observed defection. For simplicity, we focus on the first two instances when the subject is a seller following an observed defection.[18] The pseudo-r2 statistic for the *Tickets* treatment is 51.2%, which grows to 68.9% when considering only matches with feasible ticket exchange. In contrast, the *Baseline* treatment scores 7.7%. Similar results are obtained in probit regressions along the lines of the one in Table 7 where we drop demographic independent variables that subjects could not observe (interaction was anonymous) and control for individual characteristics (not reported). The pseudo-r2 statistic for the *Tickets* treatment is 47.9%, which grows to 65.9% when considering only matches with feasible ticket exchange. In contrast, the *Baseline* treatment scores 5.6%.

Table 7

There are also interesting results on the use of strategies of community enforcement of defections. If the representative subject switched from a cooperative to a punishment "mode" after seeing autarky, then the estimated coefficient of at least one of the three strategy regressors should be negative. For instance, if subjects punished by choosing *Y* only the first time they became sellers after a defection, then the sum of the estimated coefficients of the grim trigger regressor and the Lag 1 regressors should be negative for the first occurrence following a defection, and zero afterwards. The data are not consistent with the use of tit-for-tat, which is not an equilibrium strategy. The grim trigger marginal effect estimate of -0.36 is significantly different than zero at a 1% level, while all other strategy marginal effects are not significant (Table 7). These results are consistent with the notion that the average subject employed an informal sanctioning scheme based on the grim trigger strategy. The data show a sizable and persistent decline in cooperation of the average subject following an autarky outcome.[19]

Monetary exchange also promoted a redistribution of surplus from frequent defectors to

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[18] There are several ways to choose regressors to trace strategies. The specification selected has the advantage of detecting whether subjects followed strategies that are either theoretically or behaviorally relevant, such as grim trigger (Kandori, 1992) or tit-for-tat (Axelrod, 1984). We include a "grim trigger" regressor, which has value 1 in *all* periods following the first match in which *Y* was the outcome, and value 0 otherwise. We also include "Lag" regressors, which consider only the periods—after suffering a defection—in which the subject has an opportunity to punish. The "Lag 1" regressor takes value 1 at the first opportunity to punish and 0 otherwise. The "Lag 2" regressor takes value 1 at the second opportunity to punish and 0 otherwise. The regression also controls for location as we conducted half of the sessions at University of Iowa and half at Purdue University. Iowa students cooperate marginally more, although this effect is small (Table 7).

[19] The probit regression in Table 7 provides evidence for demographic effects. Male subjects are significantly more likely to cooperate than female subjects in all treatments when controlling for major, location, and risk attitude (the marginal effect is 0.142 in col.2). This is interesting because the literature has sometimes reported that women are more generous than men (e.g. Andreoni and Vesterlund, 2001, Ortmann and Tichy, 1999).

frequent cooperators. Given heterogeneous behavior, tickets can become a powerful device to ensure that subjects who do not want to cooperate cannot free ride. If offering a ticket is statistical evidence of being a cooperator, then subjects who wish to cooperate may choose to do so only in exchange for a ticket. An important consequence of monetary exchange is that the probability of a cooperative outcome improves only for those who hold tickets and falls for everyone else, so that the use of tickets redistributes surplus in an incentive-compatible way, from defectors to cooperators. Figure 4 shows how adopting the monetary exchange strategy redistributed earnings. Subjects who cooperated less than 40% as sellers earned significantly less than in the *Baseline* treatment (Mann-Whitney tests, p-value=0.003, N1=78, N2=66). Subjects who cooperated 40% or more earned significantly more (p-value=0.001, N1=88, N2=104).[20] When comparing earnings distributions in *Baseline* vs. *Tickets*, one can notice a change in the relative incentives to coordinate on cooperation relative to defection.

Figure 4

5. Monetary exchange as a substitute for reputation

There is an additional possible explanation for the use of tickets besides a coordination and redistributive motive. It has been argued that fiat money exists only to fill a record-keeping need when the past history of other participants is unknown (e.g., Ostroy and Starr, 1990, Kocherlakota, 1998). For example, autarky can be threatened if someone's record includes a past defection. Tickets in the experiment could provide some record-keeping, while maintaining anonymity in interaction, because ticket holdings could signal a subject's frequency of cooperation. To assess the empirical relevance of record-keeping and reputation in facilitating cooperation we designed and studied additional treatments.

5.1 Additional treatments

This section describes two treatments with a prototypical record-keeping institution added to the *Baseline* design (Table 1). Both treatments introduce the possibility to build a reputation through the creation of individual records while preserving anonymity of interaction. One institution (*Information Provision*) has function similar to a Better Business Bureau, where a buyer's record

[20] Earnings were adjusted to account for the uneven frequency of a subject's buyer and seller role. Figure 4 does not qualitatively change when using raw average profits.

is a public good and the seller can freely view it. The other institution (*Information Request*) is more similar to a Credit Agency, where the buyer's record is a private good and the seller must pay to view it. Neither treatment can offer as much information as would be available with public monitoring. Yet, compared to the *Tickets* treatment, better information can be supplied on the past history of other participants.

Information Provision treatment (IP). This treatment adds a post-exchange stage. After observing the outcome of the gift-giving game, the buyer can pay 1 point to truthfully report the outcome selected by her opponent (action *P*). This information is added to her opponent's *record*, which is empty in period 1 of a cycle. Alternatively, the buyer can choose not to make a report (action *NP*). The seller never sees the buyer's action in this post-exchange stage. In any given period of a cycle, the record of a subject spans the preceding six periods in that same cycle.[21] The record excludes the subject's identity and displays a summary of her history based on voluntary reports. It includes how many times: the subject was a seller, her action was not reported, her reported action was *Y* or *Z*. Before making a choice, the seller can review at no cost the record of the buyer and her own record. The buyer does not observe any record. Since records are anonymous (identities are excluded from records) random matching implies that sellers cannot directly identify a past opponent by simply looking at a record. Possible payoffs and outcomes are as in the *Baseline* treatment, with the exception that payoffs for buyers include the loss of 1 point if they report the seller's action. If no action is ever reported, then the IP treatment is equivalent to the Baseline treatment.

Information Request treatment (IR). This treatment adds a pre-exchange stage. Before the gift-giving game, the seller can pay 1 point to view the record of her opponent (action *R*). Alternatively, the seller can choose not to view the buyer's record (action *NR*). The buyer never sees the seller's action in this pre-exchange stage. As in the IP treatment, the subject's record spans the last six periods in the cycle and does not include the subject's identity. Unlike the IP treatment, the record is a summary based on the complete 6-period history of actions and states of the subject. The record displays how many times: the subject was a seller, and her action was *Y* or *Z*. Possible payoffs and outcomes are as in the *Baseline* treatment, with the exception that

[21] The expected duration of a cycle was about 14 periods. Limiting records to 6 periods allowed for some learning by insuring that an initial mistake would not permanently stain the reputation of a subject.

the seller pays 1 point to view her opponent's record.[22]

The IP and IR treatments exhibit elements of commonality. First, a subject's record includes only information about her past actions as a seller, which allows to build a reputation but does not necessarily reveal the outcome in each past period (for example, when the subject was a buyer). This means that the record of a subject cannot reveal a past autarky outcome unless that subject was the seller in *that* period and *she* defected. Second, a seller can only view the record of her current opponent, and the record does not reveal the opponent's identity (anonymity). Third, a subject's record neither includes his opponents' history, nor the histories that the subject observed. For example, the record does not say if subjects defected after observing a defection. Fourth, these institutions are two among the many possible record-keeping institutions. Yet, they provide a reasonable comparison with the tickets treatment because they are less costly than the implicit cost of using monetary exchange and they can provide more accurate information about agents' past behavior.

We now turn to theoretical considerations. First, because the grim trigger strategy is available in IR and IP treatments, we have a result similar to Proposition 2: in the IR and the IP treatment, adding record keeping does not eliminate any equilibria of the Baseline treatment because record-keeping can always be ignored. Hence, the record-keeping institutions considered do not expand the efficiency frontier.

Second, any strategy involving the use of record-keeping generates a deadweight loss that lowers the efficiency frontier for any cooperation level achieved. In the IP and IR treatments the long-run efficiency loss from creating and viewing the opponents' records is no greater than 16.7%. The maximum loss occurs when all subjects report and view the actions of all opponents, which costs 2 points out of a maximum surplus of 12 in each economy.[23] For comparison, in the *Tickets* treatment, the adoption of the monetary exchange strategy generates a larger theoretical deadweight loss (Proposition 3).

Third, *Information Provision* and *Information Request* make it possible for sellers to have accurate knowledge of the opponent's past behavior. In *Information Request*, a seller can always

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[22] The IP and IR treatments can be interpreted as introducing an institution that processes, respectively, the information truthfully provided by agents in the economy and all the available information; see Kandori (1992) for a similar interpretation. The institution marks agents who have defected and the mark is publicly observable at no cost in one case (IR), but not the other (IR).

[23] With information provision, a buyer could report only the first defection observed and still generate an accurate record. Here we do not characterize the optimal strategy for providing information and for requesting information.

view a record of the actions taken by the opponent in the last 6 periods. In *Information Provision*, accurate records can be created if buyers report the seller's action. In contrast, in the *Tickets* treatment, ticket holdings offer only an *inaccurate* record of the opponent's history of actions. Because of the randomness in meetings and in roles, holding 0 tickets may be the result of different histories. For instance, it could mean that this is someone who repeatedly refused to cooperate as a seller, or who simply ran out of tickets after being a buyer several periods in a row. Hence, even when everyone adopts the monetary exchange strategy, ticket holdings provide inaccurate records of past behavior. Increasing the number of tickets or removing bounds on holdings does not solve this basic inaccuracy problem.

5.2 Additional results

To sum up, *Tickets*, *IR*, and *IP* introduce forms of record-keeping that maintain anonymity in interaction and cannot expand the efficiency frontier relative to the *Baseline* treatment. In fact, active use of record-keeping lowers efficiency. *IP* and *IR* make available record-keeping that has the greatest accuracy, an out-of-pocket cost of use, and the theoretically lowest efficiency loss.

Result 5. *The Information Provision and Information Request treatments introduced more accurate and less costly record-keeping than tickets. The empirical deadweight loss associated to the use of record-keeping in IP, IR and Tickets was, respectively, 2.0%, 4.1% and 15.9% of total surplus.*

The cost of record keeping in the IR treatment derives from the 1 point paid by the seller to view the record of the buyer. Given the empirical frequency of requests, the average cost for the economy was 0.12 points out of 6. The cost in the IP treatment is similarly assessed.

In the *Tickets* treatment, adoption of the monetary exchange strategy generates an efficiency loss because ticket exchange is not always feasible and sellers do not cooperate unless they received a ticket. If cooperation does not take place in a match, then the surplus loss is 6 points. This loss was sometimes avoided in the experiment when sellers cooperated in unfeasible matches (Result 2). Hence, we adjust the realized surplus using the additional frequency of cooperation observed when ticket exchange is feasible (61.4% minus 12.5%). The adjustment yields an empirical loss of 2.93 points in matches where ticket exchange is unfeasible (32.7% of matches). The total efficiency loss in the average match was 0.96 points, i.e., 15.9% of surplus.

Result 6. *Cooperation rates in the Information Provision and Information Request treatments were similar or lower than in the Tickets treatment.*

Support for this result is provided in Tables 3-4 and 7. Average cooperation in the *IP* treatment was 37.5%, which is at least 9.3% lower than any other treatment (Mann-Whitney test, p-values=0.031 in baseline, 0.074 in tickets, and 0.026 in IR, n1=50, n2=50; see Table 3). In particular, there is an 11.9% gap with the *IR* treatment. Average cooperation in the *IR*, *Baseline* and *Tickets* treatments is not significantly different (Mann-Whitney test, p-value=0.97 for Baseline and 0.62 for Tickets, n1=50, n2=50). These results are confirmed when we focus on average cooperation in period 1 of each cycle (Table 4).[24] The highest period 1 cooperation is 71.0% in the *Tickets* treatment, which is significantly higher than in all other treatments (Mann-Whitney test, p-values 0.008 Baseline, 0.0001 IP, 004 IR, n1=50, n2=50). In short, this analysis suggests that in this environment cooperation is difficult to support even with record-keeping.

These results are interesting because introducing the possibility of record-keeping does not shrink the set of discount factors that supports the efficient equilibrium. After all, subjects can always avoid the use of record-keeping, though they did not in the experiment. In the IP treatment, buyers reported the seller's choice in 24.5% of instances, on average. In the IR treatment, sellers viewed the record of their buyer in 12.1% of cases, on average.

We interpret the above evidence as suggesting that tickets are not primarily valued for their record-keeping role. There exists the possibility that some record-keeping technologies will perform better than the baseline. Our result suggests that – in order to do so – such institution should likely provide a perfectly accurate record at a zero or very low cost, which effectively transforms the economy from an anonymous setting to a radically different one where relational contracts are possible and cheap.

An additional comparison across treatments involves two measures of surplus. The *net surplus* for an economy is the points earned above autarky. The *gross surplus* is the added value in the economy, i.e., the net surplus plus the cost of the institution. In the Tickets treatment, the gross surplus gives the hypothetical surplus that would have been achieved in our experimental economies had monetary exchange been feasible in all matches. The Tickets treatment achieves

[24] Economies in the IP treatment start cooperating in period 1 in 45% of the cases versus 51% of the IR and Baseline treatments (differences not statistically significant). Interestingly, this result differs from the findings in Stahl (2009), where under certain conditions a color-coded record-keeping mechanism improved cooperation.

the highest gross surplus, which is 7.53 points out of a maximum of 12, in comparison to the other treatments where it ranges from 4.50 to 5.93 points (Table 3).

We can now draw the following conclusion based on the previous results. We studied various forms of record-keeping. If improving knowledge of past behaviors through record-keeping is the key to reducing the temptation to defect, then the IR and IP treatments should exhibit a larger favorable impact on cooperation than the *Tickets* treatment. Such institutions supply better information than tickets and they do so at a lower cost (Results 5). In practice, the data reveals that *IP* and *IR* are at best ineffective in increasing cooperation relative to the *Baseline* (Result 6). In sum, our interpretation about the role of monetary exchange is that it goes beyond bridging informational gaps. Additional experiments with variations in record-keeping technologies may further corroborate this interpretation.

Did better record-keeping allow subjects to achieve similar or better coordination on the inter-temporal giving and receiving of goods compared to ticket exchange? (Result 4) The short answer is no, even if better record-keeping helped in some respects to simplify the coordination task. To see this, note that in IR having the option to pay to view the past history of the opponent allows subsets of subjects to coordinate on history-dependent strategies. For example some subjects may choose to cooperate only with those who have immaculate cooperation records, even if not everyone in the economy does so. With IP, instead, this cannot be done unless everyone in the economy coordinates on making reports and using a history-dependent strategy, because information on past actions must be created. However, neither IR nor IP helped in coordinating on out-of-equilibrium strategies. What’s more, neither IR nor IP helped with redistributing surplus from defectors to cooperators to the same extent as with tickets. A graph analogous to Figure 4 would show earnings distributions for IR and IP treatments that are qualitatively similar to the *Baseline* and qualitatively different from the *Tickets* treatment.

6. Discussion and conclusions

This study uncovered a new behavioral foundation for the use of monetary systems in promoting impersonal exchange. The availability of intrinsically worthless tickets favored the coordination on the inter-temporal giving and receiving of goods in ways that subjects were not able to achieve through decentralized community enforcement.

In an experiment, a stable population of strangers interacted in pairs with changing opponents.

The interaction consisted of an indefinite sequence of encounters where subjects could either give or receive a good. In every encounter, the subject without the good valued it more than the subject with the good; hence there was a social gain from inter-temporal cooperation. This design is new and sets this study apart from previous experiments on social dilemmas with indefinite duration. The interaction was anonymous; hence, subjects could not rely on direct reciprocity or engage in relational contracts. In all economies studied, the efficient outcome could be achieved through a social norm. Subjects could rely on decentralized community enforcement due to the indefinitely repeated interaction. On the contrary, the efficient outcome could *not* be reached through monetary exchange, i.e., by making cooperation conditional on the transfer of a ticket.

Two findings stand out. There was widespread use of intrinsically worthless tickets, even if subjects could reach efficiency through a social norm and if basing cooperation only on the exchange of tickets substantially lowered the efficiency frontier. Second, the exchange of tickets facilitated coordination on cooperative outcomes. In the laboratory economies tickets performed the function of fiat money. The data exhibit patterns of behavior coherent with the typical description of a monetary economy. Tickets acquired value endogenously even if they had no redemption value; cooperation was exchanged for tickets in a *quid pro quo* manner; the distribution of ticket holdings in the economy was close to the theoretical prediction.

Based on the behavioral findings reported in this paper, we argue that money is a powerful tool for equilibrium selection in economies that rely on impersonal exchange. Such a role of monetary systems is not in contrast with other explanations for the existence of money proposed in the literature.

A monetary system helps to select equilibria through various channels. First, monetary exchange has a fundamental behavioral role in facilitating coordination. On the one hand, it solves the *on-equilibrium* coordination problem because it allows a subset of the population to cooperate without the need to coordinate with everyone in the economy. This is especially important in heterogeneous populations and in economies of more than two subjects such as in our experiment. For instance, monetary exchange can sustain some cooperation even if just two subjects in the economy follow this strategy, independently of the behavior of others. Instead, grim trigger may not guarantee cooperation unless its adoption is universal. In addition, monetary exchange solves the *off-equilibrium* coordination problem because it removes entirely the need to coordinate on a decentralized punishment strategy to discourage defections. The seller who does not cooperate simply does not receive a ticket due to the *quid pro quo* nature of monetary exchange. Second, monetary exchange substantially raised the predictability of cooperative outcomes: strategic uncertainty of impersonal exchange was substantially lower in the *Tickets* treatment. Subjects trusted that their cooperation would be reciprocated in exchange for a ticket. Third, tickets supported a redistribution of surplus from frequent defectors to frequent cooperators. In the treatment without tickets, average earnings were the highest for frequent defectors. That was no longer true when tickets were available. While there was a modest difference in aggregate earnings between treatments, there still was a substantive motive to adopt a monetary exchange strategy for subjects interested in cooperation.

It has been argued that fiat money is nothing but a primitive form of memory and it is valued *only* because it bridges informational gaps. We compared the performance of money and other record-keeping institutions and, at least for the institutions here studied, did not find strong support for this view. Cheaper and more accurate record-keeping institutions sometimes generated lower average cooperation rates than in the treatments with and without tickets. It is left to future work a more systematic exploration of this issue.

In conclusion, this study opens a new avenue of research. Monetary exchange is a defining feature of virtually every economy and yet money plays no role in most economic models. What the literature has largely ignored, and this study has uncovered, is a role of fiat money as a tool for equilibrium selection. It may well be the behavioral foundation for the use of money.

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Tables and Figures

	Baseline		Tickets		Information Provision (IP)		Information Request (IR)	
Information	Private monitoring		Private monitoring		Seller sees summary of reported actions of opponent		Seller can pay to see summary of past actions of opponent	
Action sets:	**Seller**	**Buyer**	**Seller**	**Buyer**	**Seller**	**Buyer**	**Seller**	**Buyer**
pre-exchange	——	——	——	——	——	——	{*R*,*NR*}	——
exchange	{*Y*,*Z*}	--	{*Y*,*Z*,*Z*|1}	{0,1,1|*Z*}	{*Y*,*Z*}	——	{*Y*,*Z*}	——
post-exchange	——	——	——	——	——	{*P*, *NP*}	——	——
Earnings in points (outcome *Y*, outcome *Z*)	(8,2)	(8,20)	(8,2)	(8,20)	(8, 2)	(8,20) -1 if *P*	(8,2) -1 if *R*	(8,20)
Grim trigger supports the efficient outcome	Yes		Yes		Yes		Yes	
Session dates, location, # of periods	21.9.08, Purdue, 43 7.9.08, Iowa, 58		21.9.08, Purdue, 82 10.9.08, Iowa, 111		19.9.08, Purdue, 68 26.10.08, Iowa, 69		20.9.08, Purdue, 55 16.11.08, Iowa, 102	

Table 1: Experimental treatments

Notes: Seller was called Red in the experiment and buyer was called Blue. A subject who takes no action has an empty action set, denoted ––. Conversion rate: 10 point = \$0.25. The date format is day.month.20xx.

		Action of buyer			
		0	1	1|*Z*	No action
Action of Seller	*Y*	*Y*, No Transfer	*Y*, Transfer	*Y*, No Transfer	*Y*, No Transfer
	Z	*Z*, No Transfer	*Z*, Transfer	*Z*, Transfer	*Z*, No Transfer
	Z|1	*Y*, No Transfer	*Z*, Transfer	*Z*, Transfer	*Y*, No Transfer

Table 2: Outcomes in Tickets treatment

Notes: An outcome is a pair x, y where x=Y, Z and y=Transfer, No Transfer. Outcome Y gives 8 points to both seller and buyer; outcome Z gives 20 points to the buyer and 2 to the seller. Ticket transfer or possession generates neither earnings nor losses. Outcomes for the Baseline treatment are in the shaded area. The last column includes all outcomes when a buyer has no tickets. The first two lines include all outcomes when the seller has two tickets.

	Treatment					
	Baseline	**Tickets**			**IP**	**IR**
Cycle		All matches	Feasible	Unfeasible		
1	0.475	0.527	0.615	0.167	0.410	0.388
2	0.441	0.494	0.612	0.074	0.342	0.526
3	0.563	0.442	0.582	0.122	0.448	0.485
4	0.487	0.506	0.690	0.178	0.425	0.543
5	0.446	0.371	0.570	0.094	0.249	0.530
Overall cooperation	**0.482**	**0.468**	**0.614**	**0.125**	**0.375**	**0.494**
Net surplus (points)	5.78	5.62	--	--	4.01	5.69
Gross surplus (points)	5.78	7.53	--	--	4.50	5.93
Maximum theoretical surplus	12	12	--	--	12	12

Table 3: Average cooperation frequency: all periods

Notes: 1 obs. = 1 economy (10 obs. per cycle, per treatment). Consider an economy k=1,..,50. The mean cooperation level for an economy k=1,..,n is measured by defining the action $a_{it}^k \in \{0,1\} \equiv \{Z, Y\}$ *of a seller (red subject) i=1,2 in period t=1,..,*T^k *of the economy as an element. A cooperative action is coded as 1, and a defection is coded as 0. Therefore, average cooperation in an economy k is* $c_k = (1/2T^k)\sum_{t=1}^{T^k}\sum_{i=1}^{2} a_{it}^k$ *between zero and one, and across economies is* $c = (1/n)\sum_{k=1}^{n} c_k$ *. Thus, although economies have different length* T^k*, they are given equal weight in our measure c of average cooperation, since we consider each economy a unit of observation. To calculate gross surplus in the IP and IR treatments multiply the average cooperation rate by the maximum surplus (12 points). To obtain net surplus, subtract from gross surplus the cost of the institution, i.e., 2 points multiplied by the frequency with which buyer (in IP) or seller (in IR) used the institution.*

	Treatment			
Cycle	**Baseline**	**Tickets**	**IP**	**IR**
1	0.40	0.40	0.40	0.20
2	0.30	0.75	0.45	0.45
3	0.55	0.70	0.50	0.70
4	0.55	0.85	0.40	0.60
5	0.75	0.85	0.50	0.60
Overall frequency of cooperation	**0.51**	**0.71**	**0.45**	**0.51**
Fraction of economies with 100% cooperation	0.30	0.58	0.10	0.24
Fraction of economies with 100% defection	0.28	0.16	0.20	0.22

Table 4: Average cooperation frequency: period 1 of each cycle

Buyers	Sellers			
	0 tickets	1 ticket	2 tickets	*Total*
0 tickets	0.031	0.083	0.103	*0.217*
1 ticket	0.075	0.213	0.079	*0.367*
2 tickets	0.307	0.079	0.031	*0.417*
Total	*0.413*	*0.375*	*0.213*	*1.001*

Table 5: Empirical distribution of ticket holdings in the average economy

Notes: N=50 economies. We first compute the frequency of each occurrence by economy and then take the mean across economies. The shaded area includes cells where ticket exchange is unfeasible.

	Sellers			
Buyers	***Defect***	***Cooperate***	***Cooperate* if 1 ticket is transferred**	Total
No action available:				
feasible	--	--	--	--
unfeasible	51.6	7.0	7.7	66.3
Transfer 0				
feasible	2.3	0.1	3.5	5.9
unfeasible	12.7	2.9	0.0	15.6
Transfer 1				
feasible	2.2	0.2	1.9	4.3
unfeasible	1.6	0.3	0.0	1.9
Transfer 1 if the outcome is *Cooperate*:				
feasible	30.6	8.1	51.0	89.7
unfeasible	13.9	2.4	0.0	16.3
Total:				
feasible	35.1	8.4	56.4	100
unfeasible	79.8	12.6	7.7	100

Table 6: Frequency distribution of players' actions and feasibility of ticket exchange

Notes: All numbers are in percent. Feasible (unfeasible) refers to matches where ticket transfer is feasible (unfeasible). The shaded cells refer to feasible matches where there is a cooperative outcome and a ticket transfer. Y= defect and Z= cooperate

	All Treatments		Baseline	Tickets		IP	IR
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable: 1=cooperation 0=defection	Periods 1 only				Feasible matches only		
Treatment dummies:							
Ticket	0.238***	-0.017					
	(0.052)	(0.022)					
IP	-0.048	-0.107***					
	(0.040)	(0.040)					
IR	0.010	0.006					
	(0.104)	(0.034)					
Duration of previous cycle	0.006**	0.003***	-0.000	0.004***	0.005***	-0.003***	0.002***
	(0.003)	(0.000)	(0.008)	(0.000)	(0.000)	(0.001)	(0.000)
Cycle dummies: Cycle 2	0.142	-0.032	0.028	-0.194***	-0.197***	-0.092***	0.113***
	(0.111)	(0.052)	(0.134)	(0.011)	(0.074)	(0.028)	(0.000)
Cycle 3	0.237**	-0.046	0.117	-0.165***	-0.144	-0.080***	0.077***
	(0.119)	(0.037)	(0.117)	(0.054)	(0.183)	(0.006)	(0.014)
Cycle 4	0.221**	-0.007	0.089	-0.163***	-0.159*	-0.101	0.120***
	(0.094)	(0.037)	(0.158)	(0.003)	(0.093)	(0.088)	(0.017)
Cycle 5	0.309***	-0.134***	-0.021	-0.238***	-0.144**	-0.217***	-0.016
	(0.070)	(0.034)	(0.054)	(0.050)	(0.059)	(0.004)	(0.036)
Strategy coding: grim trigger		-0.443***	-0.416***	-0.286***	-0.155**	-0.229***	-0.535***
		(0.060)	(0.045)	(0.080)	(0.068)	(0.009)	(0.042)
Lag 1		0.065**	0.102	0.075*	0.023	0.036***	0.005
		(0.033)	(0.115)	(0.039)	(0.033)	(0.011)	(0.073)
Lag 2		-0.003	-0.007	0.074*	-0.000	-0.008	-0.027***
		(0.023)	(0.028)	(0.039)	(0.008)	(0.021)	(0.007)
Iowa location	0.112**	0.042**	0.102*	-0.016***	0.093	-0.052***	0.092***
	(0.053)	(0.021)	(0.057)	(0.002)	(0.077)	(0.001)	(0.013)
Male	0.258***	0.142***	0.112**	0.269***	0.240***	0.160***	0.098***
	(0.043)	(0.037)	(0.049)	(0.008)	(0.005)	(0.036)	(0.030)
Business major	-0.076	-0.088	-0.167	-0.258***	-0.294***	-0.211***	0.090***
	(0.108)	(0.068)	(0.273)	(0.002)	(0.020)	(0.020)	(0.034)
Engineering, Science, and Mathematics major	-0.062	-0.068	-0.154	-0.198***	-0.206***	-0.105**	-0.013***
	(0.082)	(0.074)	(0.198)	(0.043)	(0.008)	(0.044)	(0.004)
Risk neutral or low Risk aversion (questionnarie)	0.026	0.073	0.091	-0.045***	-0.083***	0.305***	-0.034
	(0.075)	(0.062)	(0.114)	(0.008)	(0.016)	(0.044)	(0.078)
High Risk aversion (questionnarie)	-0.218***	-0.092	-0.066	-0.059	-0.138**	-0.207***	0.031

	(0.075)	(0.060)	(0.149)	(0.100)	(0.062)	(0.068)	(0.059)
A ticket was transferred				0.795***	0.882***		
				(0.017)	(0.056)		
Subject's public record shows:							
at least one cooperative action						0.239***	
						(0.003)	
at least one defection action						-0.135***	
						(0.003)	
Opponent's public record shows:							
at least one cooperative action						0.157***	
						(0.010)	
at least one defection action						-0.096**	
						(0.045)	
reported cooperation rate > 50% [1]							0.415***
							(0.024)
reported defection rate > 50% [2]							-0.020
							(0.102)
Pseudo-R2	0.148	0.092	0.077	0.512	0.689	0.265	0.173
Observations	400	5880	1010	1930	1151	1370	1570

Table 7: Probit regression on individual choice to cooperate – marginal effects

*Notes: Marginal effects are computed at the mean value of regressors. Robust standard errors for the marginal effects are in parentheses computed with a cluster on each session; * significant at 10 percent; ** significant at 5 percent; *** significant at 1 percent. For a continuous variable the marginal effect measures the change in the likelihood to cooperate for an infinitesimal change of the independent variable. For a dummy variable the marginal effect measures the change in the likelihood to cooperate for a discrete change of the dummy variable. Period fixed effects are included (except in the first column) but not reported in the table (periods 2-5, 6-10, 11-17, 18-25, >25). Duration of previous cycle was set to 14.3 periods for cycle 1. Each observation refers to a seller in a pair, i.e. half of the population in each period.*

[1] This dummy variable takes value 1 when the subject asked for feedback information on her opponent, the opponent has been a seller at least once before, and the number of periods in which the opponent's **cooperation** was reported is strictly above 50% of the number of periods in which the opponent was a seller.

[2] This dummy variable takes value 1 when the subject asked for feedback information on her opponent, the opponent has been a seller at least once before, and the number of periods in which the opponent's **defection** was reported is strictly above 50% of the number of periods in which the opponent was a seller.

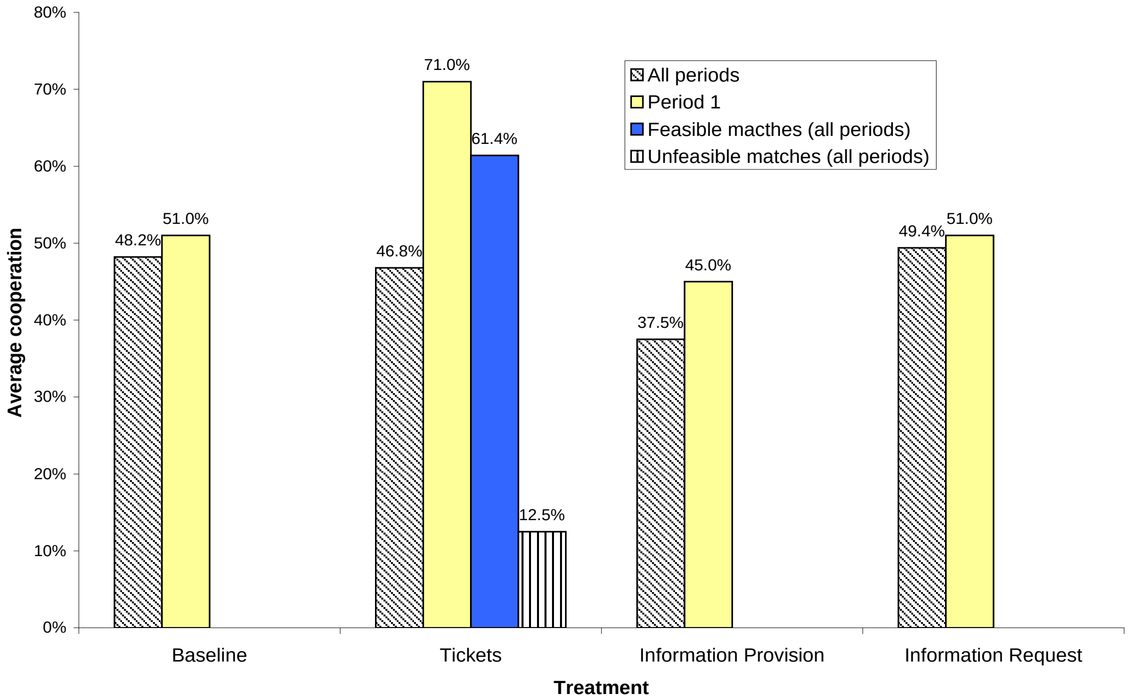

Figure 1. Cooperation by treatment

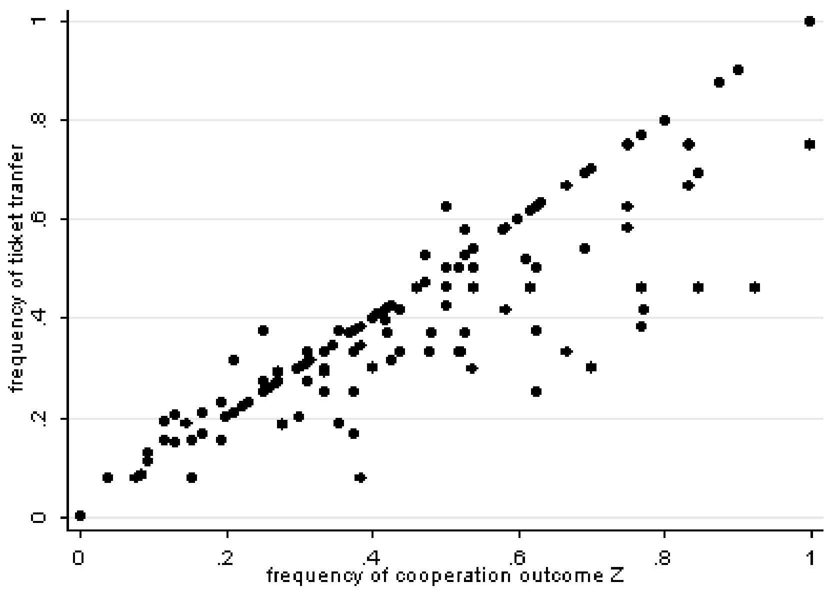

Figure 2. Cooperation by frequency of ticket transfer

Notes: N=200; 1 obs=average among all actions taken during a cycle by a subject. This statistic is not an average by economy. The frequency of cooperation counts the outcomes experienced by the participant both as a seller and as a buyer. Both giving and receiving a ticket counts as a ticket transfer.

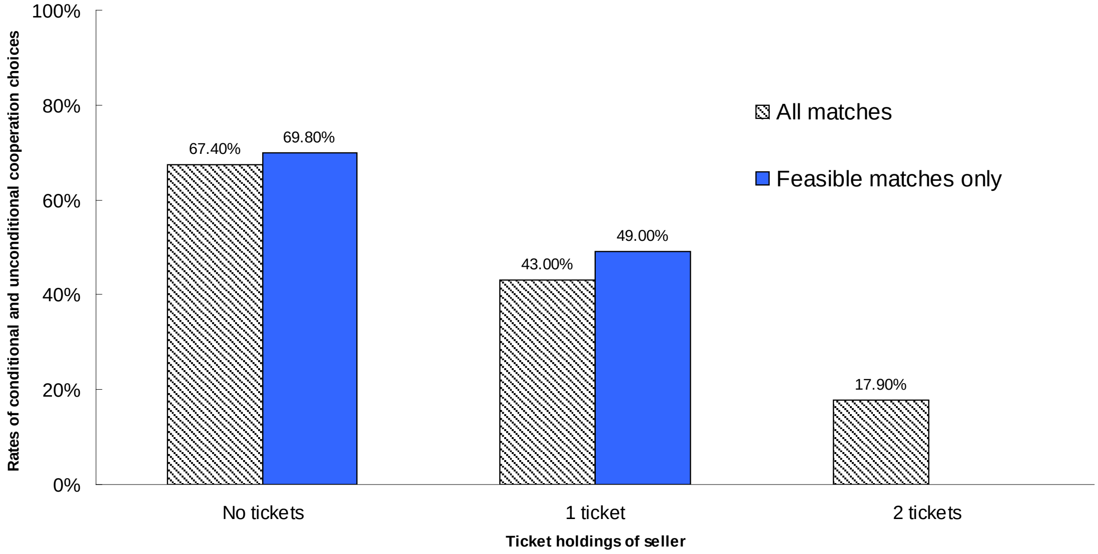

Figure 3. Cooperation rates by seller's ticket holdings

Notes: N=1930, 1151; 1 obs.=seller's choice in a period. The cooperation rate refers to the sum of unconditional and conditional cooperation choices observed (Z and Z|1).

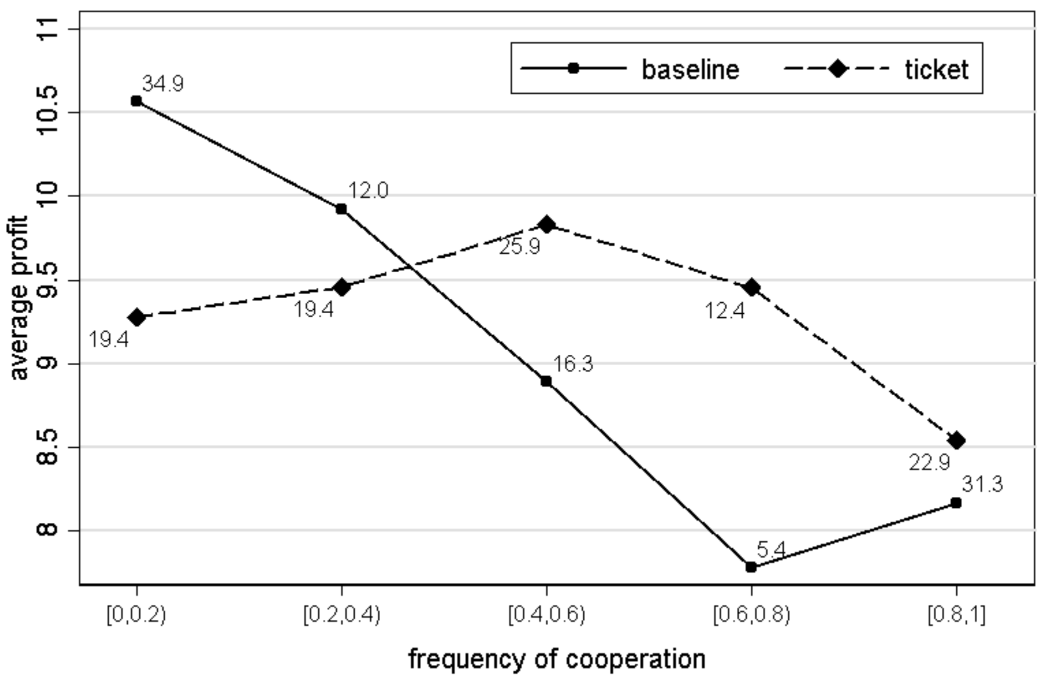

Figure 4. Cooperation rates and earnings

Notes: N=166 for Baseline and N= 170 for tickets; only obs. where subjects switch roles within the cycle are included. Average profits were adjusted to account for the frequency of roles: we separately computed average profits as buyer and as seller and then took their arithmetic average. The maximum average profit is 11 and it occurs when Z is the outcome in each period, i.e., (20+2)/2; the minimum average profit occurs when Y is the outcome in each period, i.e., (8+8)/2 Next to each data point, we report the associated percentage of observations.

Appendix A - Not for publication

1 Baseline treatment: existence of cooperative equilibrium

There are four identical agents. In each period they are matched in pairs, with uniform probability of selection. In each pair, one agent is a **seller** (red) and the other is a **buyer** (blue). The state red occurs with probability α and the state blue with probability $1-\alpha$. We set $\alpha = \frac{1}{2}$ so that selling and buying are equally likely states.

Two outcomes are possible in a match: autarky Y, and cooperation Z. In what follows we will say that if the seller chooses Z in a matched pair, then his opponent "consumes" the good of the seller. For an individual, let $u = 20$ be the stage game payoff from consuming and $-c = d = 2$ the stage game payoff when the seller chooses Z. Set $a = 8$, as the stage game payoff from autarky (the seller choose Y). Clearly, $\frac{u-c}{2} > a$. Period payoffs are geometrically discounted at rate $\beta = 0.93$. Payoffs and continuation payoffs in the game are given by expected lifetime utilities.

1.1 Equilibrium payoffs

Consider a social norm based on the grim trigger strategy. It has a rule for cooperation: a seller must always choose Z. It has also a rule for punishment: If a defection is observed, then a seller chooses autarky in all future periods, i.e., Y is selected forever after.

Suppose an equilibrium exists based on this social norm. The payoff of the representative agent is denoted

$$V = \frac{(1-\alpha)u - \alpha c}{1-\beta}. \tag{1}$$

This is simply the present value of the stream of expected period payoffs, which are time-invariant in equilibrium. To discuss existence of equilibrium we now present individual optimality conditions in and out of equilibrium.

In equilibrium cooperation is a best response for a seller if

$$-c + \beta V \geq a + \beta v_2. \tag{2}$$

The left-hand-side denotes the payoff from cooperating when everyone has always cooperated up to that point. The right-hand-side from defecting when everyone has always cooperated up to that point. The notation v_2 denotes the off-equilibrium continuation payoff in the economy where two agents have seen a defection and follow the rule of punishment of the social norm (as a seller, choose Y). Since $V > v_2$ for (2) to hold, we rewrite it as

$$\beta \geq \beta_L := \frac{a+c}{V - v_2}.$$

1.2 Out of equilibrium payoffs

Consider out of equilibrium actions when everyone follows the social norm. Clearly, out of equilibrium we have at least two defectors. Let v_4 denote the continuation payoff for any agent in an economy with four defectors (everyone defects as a seller). Clearly, since both sellers will defect we have

$$v_4 = \frac{a}{1-\beta} \tag{3}$$

and so we call v_4 the **autarky** payoff.

Now consider the case where a defection has just taken place for the first time. So there are only two defectors. For concreteness, let agent x observe a defection for the first time in period $t-1$. She believes that everyone has played cooperation up to that point. Agent x may be the one who defected, or her opponent, denoted y. Suppose that everyone will behave according to the social norm from now on. Next period t there will be two defectors (agents x and y) and two cooperators (agents in the other match who observed nothing).

The continuation payoff for agent x at the start of period t is

$$v_2 = \tfrac{1}{3}(a + \beta v_2) + \tfrac{2}{3}[(1-\alpha)(u + \beta\tfrac{v_4+v_3}{2}) + \alpha(a + \beta\tfrac{v_2+v_3}{2})]. \tag{4}$$

To see why note that with probability $\frac{1}{3}$ agent x meets again agent y (a defector), and with probability $\frac{2}{3}$ agent x meets a cooperator.

- If x meets y once again, a is the period payoff, and since no one else observed a defection next period $t+1$ there will still be two defectors. So the discounted continuation payoff is βv_2.

- If x someone other than y, then this agent is a cooperator.

– If x is a seller (with probability $\alpha = \frac{1}{2}$), then x defects and earns a. The defection is seen by her opponent but the continuation payoffs depends also on what happens in the other match. This is because the other pair is also composed of a defector (agent y) and a cooperator. If agent y is a seller, then he defects (seen by her opponent). Hence, next period we have four defectors (v_4 is the payoff). If, instead, agent y is a buyer, then there is no defection in the other match and the following period we have three defectors (v_3 is the payoff). Since y is a seller with probability $\frac{1}{2}$, then a defection occurs the other match with that probability.

– If x is a buyer (with probability $1-\alpha = \frac{1}{2}$), then he earns u. Again, the continuation payoff depends on events in the other match and, since x does not defect, we cannot have more than three defectors next period. With probability $\frac{1}{2}$ there are three defectors and there are two, otherwise.

Substituting for $\alpha = 1/2$ we rearrange (4) as

$$v_2 = \tfrac{2}{3(2-\beta)}(u + 2a + \beta\tfrac{1}{2}v_4 + \beta v_3). \tag{5}$$

To calculate v_3 consider the case when, at the beginning of some date, agent x is one of three defectors (i.e., agents who have seen or implemented a defection Y). Suppose that everyone plays the social norm. The payoff to agent x is

$$v_3 = \tfrac{1}{3}\left[\tfrac{1}{2}(u + \beta v_3) + \tfrac{1}{2}(a + \beta v_4)\right] + \tfrac{2}{3}(a + \beta\tfrac{v_4+v_3}{2}), \tag{6}$$

because with probability $\frac{1}{3}$ agent x meets a cooperator, and with probability $\frac{2}{3}$ she meets a defector.

- If agent x meets a cooperator, then her period payoff depends on whether she is a seller or a buyer. Her continuation payoff depends also on this because only if she sells will the economy move to the state with four defectors. Indeed, the other match has two defectors.

- If agent x meets a defector. Then she always earns a but the continuation payoff depends on whether the cooperator in the other match is a buyer. If that's the case (with probability 1/2), then the economy transitions to a state with four defectors. Otherwise, it will remain in a state with three defectors.

Rearranging (6) we have

$$v_3 = \frac{1}{3(2-\beta)}(u + 5a + 3\beta v_4).$$

Using the above in (4) we have

$$v_2 = \tfrac{2}{3(2-\beta)^2}\{(u+2a)(2-\beta) + \beta[\tfrac{(2+\beta)a}{2(1-\beta)} + \tfrac{u+5a}{3}]\}. \tag{7}$$

We can now find a condition such that defecting in equilibrium is individually sub-optimal

Lemma 1 *There exists a non-trivial interval* $(\beta_L, 1)$ *such that if* $\beta \in (\beta_L, 1)$, *then (2) holds.*

Proof of Lemma 1. Rewrite (2) as $\frac{a+c}{v_2} \leq \beta(\frac{V}{v_2} - 1)$. As $\beta \to 0$ we have $V \to \frac{u-c}{2}$ and $v_2 \to \frac{u+2a}{3}$. So, clearly, as $\beta \to 0$ then (2) is violated for any $a \geq 0$ and $c < 0$. Notice that $\frac{\partial v_2}{\partial \beta}, \frac{\partial V}{\partial \beta} > 0$. As $\beta \to 1$, we have $v_2 \to \infty$ and $V \to \infty$. It should be clear that as $\beta \to 1$ then $\frac{a+c}{v_2} \to 0$. In addition, the RHS of the inequality converges to a positive quantity since, as $\beta \to 1$, then $\frac{V}{v_2} \to \frac{u-c}{2a} > 1$, given our initial assumption. We conclude that there exists a β_L sufficiently close to one such that (2) holds for all $\beta \in (\beta_L, 1)$, with strict inequality.

1.3 Deviating out of equilibrium

Now we find conditions under which it is optimal to follow the rule of punishment after having observed a defection. The rationale for this is that by not defecting a seller can slow down the contagion, which may be beneficial to the agent.

Suppose agent x observes a deviation for the first time in a match with agent y (who defects does not matter). Consider now the date when agent x is a seller, for the first time, after observing the defection in the match with y. This event may happen quite some time after observing the defection (role assignment is probabilistic) so it is possible that everyone else in the economy has also observed the defection because y had a chance to defect. It is also possible that y never had a chance to defect, so the economy still has two people who observed a defection. This scenario certainly occurs if x is a seller the period after observing the defection.

Consider the following deviation. Agent x but refuses to choose Y as a seller and, instead, she cooperates. She will follow the social norm for punishment afterward (one-time deviations). The rationale for this is that she can slow down the contagion to full autarky, hence enjoy some payoffs u for a little longer.

Clearly, this deviation is suboptimal if the economy has already three defectors since no one will ever cooperate. The best-case scenario is when the economy has only two defectors. Hence, consider this case by supposing that agent x is a seller the period immediately after observing her first defection,

Choosing to deviate from the social norm out of equilibrium (choosing Y) is a best response if

$$a + \beta(\tfrac{1}{3}v_2 + \tfrac{2}{3}\tfrac{v_3+v_4}{2}) \geq -c + \beta(\tfrac{1}{3}v_2 + \tfrac{2}{3}\tfrac{v_2+v_3}{2}). \tag{8}$$

- Consider the LHS of (8), which is when x follows the social norm, out of equilibrium. Since agent x is a seller she will defect, generating a period payoff. The continuation payoff depends on whom she meets. With probability $\frac{1}{3}$ agent x meets y, the deviator met earlier. In this case the continuation payoff is v_2 since the other match has two cooperators. If, instead, agent x meets a cooperator (probability $\frac{2}{3}$) then the economy will have three defectors only if in the other match the defector is not a seller (with probability $\frac{1}{2}$).

- Consider the RHS of (8), which is when x does not defect today (though she should). Instead, she chooses Z today, so her period payoff is $-c$, and will choose Y forever after. Her continuation payoff depends once again on whom she meets. If she meets agent y, the other defector, then next period there will be again two defectors (her and agent y). This occurs with probability $\frac{1}{3}$. If, instead, agent x meets a cooperator, with probability $\frac{2}{3}$ next period the economy has 2 or 3 defectors depending on what happens in the other match. With probability $\frac{1}{2}$ a defection occurs in the other match (agent y is a seller).

Inequality (8) can be rearranged as

$$a + c \geq \frac{\beta}{3}(v_2 - v_4). \tag{9}$$

Recalling that if it is optimal for agent x to defect out of equilibrium after having observed an initial defection (i.e., when there are two defectors, including agent x), then it will also be optimal to defect after having observed more than one defection (i.e., when there are more than two defectors, including agent x).

Since $v_2 > v_4$ for (9) to hold, we rewrite it as

$$\beta \leq \beta_H := \frac{3(a+c)}{v_2 - v_4}.$$

Proposition 2 *For the parameterization $u = 20$, $a = 8$ and $-c = 2$ the grim trigger strategy is an equilibrium for all $\beta \geq 0.808$.*

Proof: Inserting $u = 20$, $-c = 2$ and $a = 8$ we numerically find $\beta_L = 0.808$ and $\beta_H = 1.2$.

2 The long-run distribution of tickets

Conjecture that everyone adopts the fiat monetary exchange strategy. The distribution of tickets in the economy varies from period to period, depending on the distribution at the start of a period and the random matching. Given a constant supply of four tickets, there can be 3 possible distributions (states) at the start of a period denoted

$$d_1 = (2, 2, 0, 0),\ d_2 = (2, 1, 1, 0),\ d_3 = (1, 1, 1, 1).$$

Let $p_i(t)$ denote the probability that state $i = 1, 2, 3$ is realized in period t and, since we want to study long-run outcomes, consider long-run probabilities, i.e., $p_i(t) = p_i(t + 1) = p_i$.

Suppose the distribution is $d_1 = (2, 2, 0, 0)$**.** Three cases arise, denoted d_{1a}, d_{1b}, d_{1c}, because buyer (B) and seller (S) roles are randomly assigned:

	B	B	S	S	
d_{1a} :	2	2	0	0	(exchange always **feasible**)
d_{1b} :	2	0	2	0	(exchange **can be** unfeasible)
d_{1c} :	0	0	2	2	(exchange always **unfeasible**)

Because buyer and seller roles are equally probable for each player, each of these three distributions arises with probability 1/3. Given d_{1a}, ticket exchange is always feasible. Given d_{1c} ticket exchange is never feasible. Given d_{1b}, there are two cases to consider, each of which is equally likely, depending on random matching results. Denote $(B = x, S = y)$ the ticket holdings x, y in a match. We have

$\{(B = 2, S = 2), (B = 0, S = 0)\}$ (exchange always **unfeasible**)

$\{(B = 2, S = 0), (B = 0, S = 2)\}$ (exchange **feasible** in 1 match)

Let $p_{i,k}$ denote the probability of reaching state $i = 1, 2, 3$ conditional on being in state $k = 1, 2, 3$. The discussion above implies

$$(p_{1,1}, p_{2,1}, p_{3,1}) = (\frac{1}{2}, \frac{1}{6}, \frac{1}{3}).$$

Suppose the distribution is $d_2 = (2,1,1,0)$**.** Three possible cases arise each with probability 1/3:

$$\begin{array}{llll} & B\,B\,S\,S & \\ d_{2a}: & 2\;\;1\;\;1\;\;0 & \text{(exchange always } \textbf{feasible}\text{)} \\ d_{2b}: & 2\;\;0\;\;1\;\;1 & \text{(exchange } \textbf{feasible} \text{ in 1 match)} \\ d_{2c}: & 1\;\;0\;\;2\;\;1 & \text{(exchange } \textbf{can be} \text{ unfeasible)} \end{array}$$

Given d_{2a}, ticket exchange is always feasible and we go back to the same distribution d_2. Given d_{2b}, ticket exchange is unfeasible in one match, and we also go back to the same distribution of tickets d_2. Given d_{2c}, two equally probable cases may arise:

$$\begin{array}{l} \{(B=1, S=2), (B=0, S=1)\} \text{ (exchange always } \textbf{unfeasible}\text{)} \\ \{(B=1, S=1), (B=0, S=2)\} \text{ (exchange } \textbf{feasible} \text{ in 1 match).} \end{array}$$

From the discussion above, we have

$$(p_{1,2}, p_{2,2}, p_{3,2}) = (\frac{1}{6}, \frac{5}{6}, 0).$$

Suppose the distribution is $d_3 = (1,1,1,1)$. Ticket exchange is feasible in every match, so

$$(p_{1,3}, p_{2,3}, p_{3,3}) = (1,0,0).$$

We can now calculate the long-run distribution of tickets, i.e., the unconditional probability of being in state i. This must satisfy $p_i(t+1) = p_i(t) = p_i$ for all i and all t, hence $\{p_i\}$ must solve $p_3 = 1 - p_1 - p_2$ and $p_i = \sum_{k=1}^{3} p_k p_{i,k}$ for each $i = 1,2,3$. Since one equation is redundant, we must have

$$\begin{aligned} p_1 &= p_1 p_{1,1} + p_2 p_{1,2} + (1 - p_1 - p_2) p_{1,3} \\ p_2 &= p_1 p_{2,1} + p_2 p_{2,2}. \end{aligned}$$

Substituting for $p_{i,j}$ from above, we have

$$p_1 = p_2 = p = 3/7 \;\text{ and } p_3 = 1/7.$$

To calculate the unconditional probability distribution of tickets in the economy we proceed as follows. Let m_i denote the probability that in the long-run an agent randomly selected from the population has $i = 1, 2, 3$ tickets. We have:

$$\begin{aligned} m_0 &:= p_1\tfrac{1}{2} + p_2\tfrac{1}{4} && = 9/28 && \simeq 0.321 \\ m_1 &:= p_2\tfrac{1}{2} + p_3 && = 1 - 9/14 && \simeq 0.357 \\ m_2 &:= 1 - m_0 - m_1 && = 9/28 && \simeq 0.321. \end{aligned} \tag{10}$$

To explain (10), consider the equation for m_0. Holdings of zero tickets are observed only in states 1 and 2. Each of these states occurs with (unconditional) probability p. In state 1 only two players out of four have 0 tickets. Hence the probability of observing an agent with zero tickets is 0.50. In state 2 , only one agent out of four has 0 ticket holdings. The probability of observing 0 ticket holdings is thus 0.25. The second equation in (10) can be similarly explained. In the experiment we have $(m_0, m_1, m_2) = (0.315, 0.371, .315)$ as reported in Table 7.

The long-run fraction of matches in which ticket exchange is unfeasible can now be calculated. Ticket exchange may be unfeasible only in states 1 and 2. Consider state 1. Ticket exchange (i) is always unfeasible if d_{1c} is the distribution, (ii) is never unfeasible if d_{1a} is the distribution, while (iii) if d_{1b} is the distribution then in one subcase ticket exchange is always unfeasible, and in the other it is unfeasible only in one match (each subcases is equally likely. Now recall that the substates d_{1i}, $i = a, b, c$, are equally probable. Consequently, if we are in state 1, the anticipated proportion of matches in which exchange is unfeasible is denoted ϕ_1 where

$$\phi_1 := \Pr[d_{1c}] + \Pr[d_{1b}] \times \left(\frac{1}{2} + \frac{1}{2} \times \frac{1}{2}\right) \simeq 58.33\%.$$

A similar approach applied to state 2 gives us that the anticipated proportion of matches in which exchange is unfeasible is

$$\phi_2 := \Pr[d_{2b}]\frac{1}{2} + \Pr[d_{2c}] \times \left(\frac{1}{2} + \frac{1}{2} \times \frac{1}{2}\right) \simeq 41.66\%.$$

Considering that states 1 and 2 occurs with probability $p_1 = p_2 = p$, the expected fraction of matches in which ticket exchange is unfeasible, in the long, run is given by:

$$p_1\phi_1 + p_2\phi_2$$

which amounts to p once we substitute for the exact values of ϕ_1 and ϕ_2.

3 Long-run monetary equilibrium in the Tickets treatment

Consider the following strategy: in a match a seller chooses Z conditional on receiving one unit of money; a buyer offers one unit of money conditional on the seller choosing Z. Otherwise Y is the outcome. We conjecture existence of a long-run equilibrium in which this strategy will be adopted by everybody, but someone with 2 or more ticket. More precisely, conjecture that someone with 2 or more tickets will not sell for one more ticket. The probability of being a seller in a match is $1/2$.

To focus on long-run equilibrium we must calculate the long-run value of tickets as an unconditional expectation, considering the long-run distribution of tickets. Let m_i denote the long-run probability that a seller is matched to a buyer who has $i = 0, 1, 2$ units of money. By virtue of our conjecture that in equilibrium sellers sells only if they have less than 2 tickets, then m_j are given by (10). Denote by V_i the long-run expected value of holding i tickets. It can be written recursively as:

$$\begin{aligned}
V_2 &= a + \beta V_2 + (1 - \tfrac{1}{2})(1 - m_2)[u - a - \beta(V_2 - V_1)] \\
V_1 &= a + \beta V_1 + \tfrac{1}{2}(1 - m_0)[-c - a + \beta(V_2 - V_1)] + (1 - \tfrac{1}{2})(1 - m_2)[u - a - \beta(V_1 - V_0)] \\
V_0 &= a + \beta V_0 + \tfrac{1}{2}(1 - m_0)[-c - a + \beta(V_1 - V_0)]
\end{aligned} \tag{11}$$

To explain how these expression are derived, consider V_1. Each agent is matched in each period and if an agent is a seller (with probability $\frac{1}{2}$), then the opponent is a buyer, and vice-versa. The agent can always assure himself the autarky payoff $a + \beta V_1$. In addition, the agent can earn some surplus over autarky. If the agent is a seller he cooperates in exchange for one ticket only if he meets someone who has tickets, with probability $1 - m_0$. Choosing Z implies utility $-c$ plus continuation payoff βV_2 because a ticket is earned. The opportunity cost is the autarky payoff $a + \beta V_1$. Hence the surplus to the agent as a seller is $-c - a + \beta(V_2 - V_1)$. With probability $1 - \frac{1}{2}$ the agent is a buyer enjoying a surplus $u - a - \beta(V_1 - V_0)$ only if he meets someone who has less than two units of money, with probability $1 - m_2$.

In order for the monetary exchange strategy to be an equilibrium spending a unit of money must be individually optimal for buyers, and cooperating in exchange for money must be individually optimal for a seller, i.e.,

$$\beta(V_{i+1} - V_i) \leq u - a \quad \text{and} \quad a + c \leq \beta(V_{i+1} - V_i) \ \text{ for } \ i = 0, 1. \tag{12}$$

So, to prove that the conjectured monetary equilibrium indeed exists, we need to find conditions, in terms of the parameters of the model, sufficient to satisfy the expressions in (12).

Note that if (12) hold then $V_2 - V_1 \geq V_1 - V_0$. To prove it simply observe that (11) implies

$$\begin{aligned} V_2 - V_1 \quad &= \phi[\tfrac{1}{2}(1 - m_0)(a + c) + (1 - \tfrac{1}{2})(1 - m_2)\beta(V_1 - V_0)] \\ V_1 - V_0 \quad &= \phi[\tfrac{1}{2}(1 - m_0)\beta(V_2 - V_1) + (1 - \tfrac{1}{2})(1 - m_2)(u - a)], \end{aligned} \tag{13}$$

where we define

$$\phi := \frac{1}{1 - \beta[\frac{1}{2}m_0 + (1 - \frac{1}{2})m_2]}.$$

Consequently, we must only check two inequalities in (12), i.e.,

$$\beta(V_1 - V_0) \leq u - a \ \text{ and } a + c \leq \beta(V_2 - V_1). \tag{14}$$

If the above are satisfied, then (12) is satisfied. Now note that the expressions in (14) can be rewritten as

$$a \leq \min(u - \beta(V_1 - V_0), -c + \beta(V_2 - V_1)).$$

Hence, in general there is only one condition to check. We claim that $a \leq -c + \beta(V_2 - V_1)$ is the binding condition. We prove it by contradiction. Suppose that we have a monetary equilibrium where $a \leq -c + \beta(V_2 - V_1)$ but $a = u - \beta(V_1 - V_0)$, i.e., the second inequality is the one that binds.

But if $0 = u - a - \beta(V_1 - V_0)$, then (11) implies $V_1 \leq V_0$ (because $V_1 - V_0 \geq V_2 - V_1$). But this contradicts the conjecture that $a = u - \beta(V_1 - V_0)$ because $a < u$. Hence, we can only have $a = -c + \beta(V_2 - V_1)$ and $0 \leq u - a - \beta(V_1 - V_0)$. To sum up, to find parameters for the existence of a monetary equilibrium we must check

$$0 \leq -a - c + \beta(V_2 - V_1). \tag{15}$$

This condition simply says that a seller with one unit of money will choose to cooperate in exchange for another unit of money. We can rewrite $V_2 - V_1$ as

$$V_2 - V_1 = \frac{\phi[\frac{1}{2}(1-m_0)(a+c) + \phi(1-\frac{1}{2})^2(1-m_2)^2(u-a)\beta]}{1-\phi^2(1-\frac{1}{2})(1-m_2)\beta^2\frac{1}{2}(1-m_0)}. \tag{16}$$

A monetary equilibrium exists both for the case of the theoretical distribution in (10) as well as for the case of the empirical distribution. The right hand side in (15) is 0.448, for the theoretical distribution, and 0.446 for the empirical distribution.

To prove that in equilibrium the ticket holding constraint is not binding, consider a case when, out of equilibrium an agent has three instead of two tickets. Hence,

$$V_3 \quad = a + \beta V_3 + (1-\tfrac{1}{2})(1-m_2)[u - a - \beta(V_3 - V_2)],$$

because this agent will buy if he has a chance but will not sell. Proceeding as above we have

$$V_3 - V_2 = \frac{\frac{1}{2}m_0\beta(V_2 - V_1)}{1-\beta+\frac{1}{2}m_0\beta}.$$

A seller with 2 tickets will not sell if $-c+\beta V_3 < a+\beta V_2$, which implies $\beta(V_3 - V_2) < a+c$, which can be rewritten as

$$\frac{\frac{1}{2}m_0\beta^2(V_2 - V_1)}{1-\beta+\frac{1}{2}m_0\beta} < a + c. \tag{17}$$

Using $V_2 - V_1$ from (16) one can verify that inequality (17) is satisfied for the parameters chosen in the experiment.

Appendix C – Not for publication

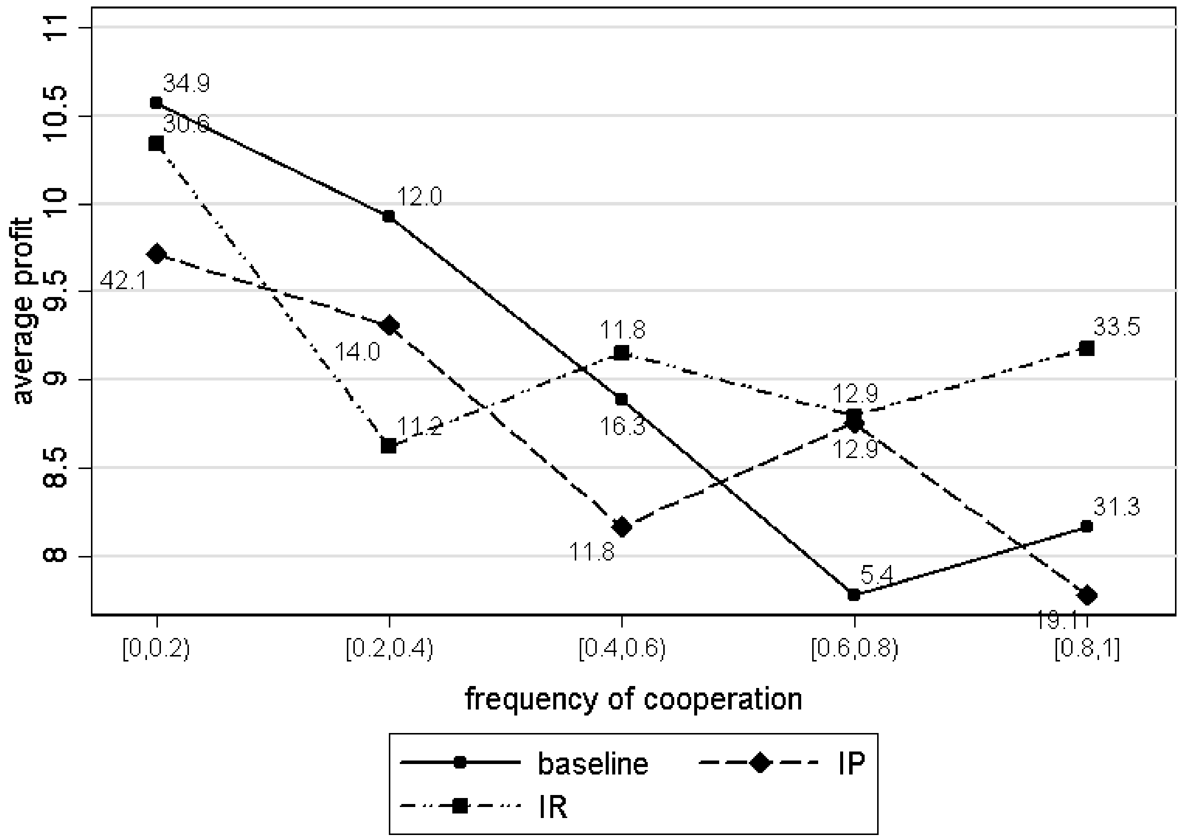

Figure C1. Cooperation rates and earnings

Notes: only observations where subjects switched roles within the cycle are included (about 170 per treatment). Average profits were adjusted to account for the frequency of roles: we separately computed average profits as buyer and as seller and then took their arithmetic average. The maximum average profit is 11 and it occurs when Z is the outcome in each period, i.e., (20+2)/2; the minimum average profit occurs when Y is the outcome in each period, i.e., (8+8)/2 Next to each data point, we report the associated percentage of observations.

Alma Mater Studiorum - Università di Bologna
DEPARTMENT OF ECONOMICS

Strada Maggiore 45
40125 Bologna - Italy
Tel. +39 051 2092604
Fax +39 051 2092664
http://www.dse.unibo.it