

Institutions for Long-run Cooperation: Experiments on Markets with Frictions*

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Abstract

We study experimental economies of indefinite duration where randomly matched subjects have an opportunity to cooperate. We evaluate how knowledge of past behavior (record-keeping) affects outcomes relative to a baseline treatment where opponents' past actions are unobservable. Three prototypical record-keeping institutions are considered. Subjects can either: purchase a record of the opponent's past actions; contribute to make public the opponent's record of actions; hold and exchange intrinsically worthless tickets. In theory, neither institution is necessary or sufficient to support the efficient outcome. In practice, relative to the baseline treatment: (1) the possibility to buy private records of actions leads to no significant increase in cooperation, (2) the possibility to create public records of actions brings about a cooperation decline, and (3) with tickets monetary exchange emerges and greatly facilitates coordination on cooperation.

Keywords: gift-giving, intertemporal exchange, information, money, folk theorem, repeated games

JEL codes: C90, C70, D80

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1. Introduction

Impersonal exchange is a fundamental trait of developed market economies (Granovetter, 1985; North, 1990; Seabright, 2004). Unlike personal exchange, it is facilitated by state enforcement, monetary exchange, and other institutions, and it does not require high levels of information about others' past behavior. In developed economies, impersonal exchange is often the only practical alternative because of social distance and anonymity in interactions. Consequently, if trade frictions hinder impersonal exchange, then opportunities for mutual gain may be lost.

This paper is an experimental study about the role of institutions that can facilitate impersonal exchange by increasing information on past behaviors. We refer to them as "record-keeping" institutions. A basic insight from the theoretical literature is that institutions are useful if they help to expand the efficiency frontier, but are unnecessary if decentralized enforcement is enough to police deviations (Milgrom et al., 1990, p.21). None of the record-keeping institutions we consider is essential to reach efficiency. Our investigation focuses on two other functions of institutions: promoting coordination on a socially desirable outcomes and redistributing surplus.

To model impersonal exchange, we adopt an infinitely repeated game with random matching. This theoretical platform is common in micro as well as macro models of decentralized trade. In the experiment, strangers interact locally, either giving or receiving goods, and in the long-run. Stranger subjects remain anonymous because they cannot observe the opponent's identity and they are randomly rematched after each encounter. The interaction is local because there is private monitoring, hence subjects observe only outcomes in their pair but not in the rest of the economy. The interaction has a long-run horizon, which is implemented through a random stopping rule. In these economies exchange may be difficult but is possible: according to the folk theorems in Kandori (1992) and Ellison (1994), there exist multiple equilibria, characterized by various degrees of efficiency.

Difficulties with impersonal exchange are at the heart not only of the microeconomic literature on repeated games and social norms but also of the macroeconomic literature on markets with *frictions* (e.g., Diamond, 1982). Frictions are obstacles to the realization of mutually beneficial exchanges, such as lack of information about identities and past behaviors

of others, difficulties in coordinating trade, or limitations in enforcement and punishment. Frictions open the door to inefficient outcomes because they introduce incentives for opportunistic behavior, prevent exchange based on relational contracts or direct reciprocity, and so remove strong and empirically-relevant motivational forces for cooperation in society.¹

Improving knowledge of histories is a recurrent theme in the theoretical microeconomic literature of repeated games and social norms, and in the literature of matching models of trade and money. The basic insight from these literatures is that better record-keeping helps subjects to capture gains from inter-temporal cooperation and expands the efficiency frontier. In monetary theory, for instance, fiat money has value because it is a record-keeping device and a primitive form of memory (e.g., Ostroy and Starr, 1990, Kocherlakota, 1998). Our investigation focuses on the role of record-keeping institutions in promoting *coordination* on socially desirable outcomes. The issue of coordination emerges because indefinite repetition theoretically supports multiple equilibria. Even if efficiency is within theoretical reach, achieving it in practice through impersonal exchange may be difficult (e.g., Schwarz et al., 2000, Camera and Casari, 2009, Duffy and Ochs, 2009), even in simple games and small groups (e.g., Cooper et al., 1990, Brandts and Cooper, 2006). Yet, this coordination role has received little attention in the theoretical literature, where often the implicit assumption is that agents will coordinate on the most efficient equilibrium outcome. Put simply, an institution is considered irrelevant (inessential) if removing it does not alter the equilibrium set.

We report three main findings. First, some record-keeping institutions had a negative impact on cooperation rates. In the *Information Provision* treatment, subjects had the costly option to individually contribute to create accurate public records of their opponents' actions, as when a Better Business Bureau is available. Average earnings and cooperation rates declined with respect to the baseline treatment (Result 4). Second, unsophisticated record-keeping institutions had a great impact on coordination on cooperation. In the *Tickets* treatment, subjects could hold and exchange worthless electronic objects. Tickets were exchanged and this promoted coordination on cooperative play (Results 2 and 3) even if full cooperation could be theoretically achieved only without using tickets. Third, the data

¹ This has been extensively documented in the experimental literature. See Berg et al., 1995, Henrich et al, 2004, Brown, et al. 2004. In the theoretical literature see for instance the discussion in Krasa and Villamil (2000).

gathered suggest a role for fiat money that goes beyond bridging informational gaps. The treatment with *Information Request* allowed subjects to see the opponent's record of actions, as when a Rating Agency exists, at a lower cost and with greater accuracy than in the *Tickets* treatment. Yet, cooperation rates did not improve.

These findings contribute to the experimental literatures on cooperation and on repeated games, as well as to a small set of studies on fiat money. In particular, experiments with fiat money share one or more of the following features. Either money has redemption value (e.g., Lian and Plott 1988, Lim, et al. 1994, Marimon and Sunder 1994, Camera et al. 2003), the use of money expands the efficiency frontier (e.g., Duffy and Ochs, 2002), or subjects interact for a finite duration in competitive markets (e.g., McCabe 1989, Deck, et al. 2006). A novelty of our design is to encompass three features : (i) money has neither intrinsic nor redemption value; (ii) the efficient allocation is an equilibrium but monetary equilibrium is inefficient; (iii) subjects interact indefinitely, anonymously, and in pairs formed at random.

The paper proceeds as follow. Section 2 presents the experimental design. Section 3 includes the theoretical predictions. Section 4 illustrates the results. Section 5 reviews the literature while Section 6 concludes.

2. Experimental design

The experiment has four treatments that are illustrated in Table 1. The baseline treatment is a gift-giving game with private monitoring. In each of the other treatments we add a prototypical economic institution to the baseline treatment: information provision, information requests, and intrinsically worthless tickets.

The stage game in the baseline treatment. Consider the following gift-giving game between a seller (red) and a buyer (blue). The seller chooses one out of two actions: outcome Y (a choice called *defection* or *autarky*) and outcome Z (a choice called *cooperation*). The buyer has no action to take. We refer to this as an exchange. The payoffs for the seller and the buyer are, respectively, (a, a) if Y and (d, u) if Z . Here $a > 0$ is the autarky payoff, $d \in (0, a)$ is the seller's payoff, and u is the payoff to a buyer who receives a transfer, with $2a < u + d$. In the experiment $d=2$, $a=8$, and $u=20$. The dominant strategy for the seller is autarky, Y . Total surplus is maximum when the seller cooperates, i.e. when the outcome is Z .

The supergame. We consider “economies” composed of four players 1,2,3 and 4 who interact for an indefinite number of periods denoted $t = 1,2,\dots$. Participants are randomly paired to play the gift-giving game earlier described (shaded area in Table 2).

A supergame (or *cycle*) consists of an indefinite interaction among subjects achieved by a random continuation rule, as introduced by Roth and Murnighan (1978). A supergame that has reached period t continues into $t + 1$ with a probability $\delta \in (0,1)$ 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, and we set $\delta = 0.93$, 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 choose Z . Thus, we refer to this outcome as the *efficient* or fully cooperative outcome. If all sellers in the economy select Y , then we say that the outcome is inefficient.

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, round-robin fashion. More precisely, 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. Subjects were informed that no two participants ever interacted together for more than one cycle, though were not told how groups were created.

Participants in an economy interacted in random pairs according to the following matching protocol within a supergame.² At the beginning of each period of a cycle, the economy was randomly divided into two pairs of participants, i.e., each subject faced one opponent (called “match” in the experiment). There are three ways to pair participants in an economy, $\{12, 34\}$, $\{13, 24\}$, or $\{14, 32\}$. In each period one pairing was randomly chosen

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.

with equal probability, so a subject had one third probability of meeting anyone else in each period of a cycle. In each pair one player is a seller (red) and one is a buyer (blue) decided each period by a coin flip. For the entire cycle a subject interacted exclusively with the members of her economy. By design, cycles terminated simultaneously for all economies. In each period, every economy had two red and two blue subjects. Once pairs were formed, the red and blue roles in each pair were assigned through a (computer-determined) coin flip. This random role assignment implied that subjects could change role from period to period.³

	Baseline		Tickets		Information Provision (IP)		Information Request (IR)	
Information	Private monitoring		See tickets of opponent		Red sees summary of reported actions of opponent		Red 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)	(8,2)	(8,20)
Session dates, location,	21.9.08, Purdue, 43		21.9.08, Purdue, 82		19.9.08, Purdue, 68		20.9.08, Purdue, 55	
# of periods	7.9.08, Iowa, 58		10.9.08, Iowa, 111		26.10.08, Iowa, 69		16.11.08, Iowa, 102	

Table 1: Experimental treatments

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

Information Provision Treatment (IP). This treatment adds a post-exchange stage where, after observing the outcome of the gift-giving game, the buyer can pay 1 point to truthfully report the action of her opponent or, equivalently, the outcome selected by her opponent (action *P*). This information is added to the *record* of her opponent. Alternatively, the buyer can choose not to make a report (action *NP*). The seller never sees the buyer's action in this

³ The random role assignment captures the notion of an economy populated by ex-ante homogeneous agents, as is typical in random matching models of exchange. An alternative is to fix or have deterministic alternation of roles while maintaining random matching, which behaviorally favors coordination on cooperation.

post-exchange stage. In any given period of a cycle, the record of a subject spans the preceding six periods in that same cycle. 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 red, her action was not reported, her reported action was Y , and her reported action was Z . Before making a choice, the seller can review at no cost the record of her blue *opponent* and her own record. Blue does not observe any record. Note that since records are anonymous (identities are excluded from the subjects' records) random matching implies that red subjects cannot directly identify past opponents by looking at their record. No records exist in period 1 of a cycle. Possible payoffs and outcomes are as in the baseline treatment, with the exception that payoffs for blue include the loss of 1 point when the buyer chooses to report the opponent's action (Table 1). Note that if no action is ever reported, then the IP treatment is equivalent to the baseline treatment with private monitoring.

Information Request Treatment (IR). This treatment adds a pre-exchange stage where 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 such a 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. However, 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 red, her action was Y , and her action was Z . Once again, possible payoffs and outcomes are as in the baseline treatment, with the exception that payoffs for red include the loss of 1 point when red chooses to view her opponent's record (Table 1).⁴

Hence, in the IP treatment the information on past actions available to subjects is a public good that is voluntarily provided. In the IR treatment, instead, the information on past actions available to subjects is a private good that is exogenously provided. The IP and IR treatments share the following elements of commonality. A seller cannot view the record of subjects in another match. A subject's record includes only information about her past actions (not the

⁴ 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 (IP).

outcome). This means that the record of a subject cannot reveal a past autarky outcome unless that subject was the seller in that period and he defected. Second, a record can “mark” a subject as defector but cannot uniquely identify him (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 whether the subject defected after observing a defection. Neither treatment can offer as much information as would be available with public monitoring.

Ticket Treatment (T). Each blue subject was endowed with two electronic objects, called “tickets,” in period 1 of each cycle. Tickets could be carried over to the next period but not to the next cycle. They are intrinsically worthless because holding them yielded no extra points or dollars, and they could not be redeemed for points or dollars at the end of the cycle. A buyer who had tickets could transfer one ticket to her opponent. The buyer could either keep the ticket (action 0), unconditionally transfer it (action 1), or transfer it conditional on the outcome being Z (action $1|Z$); hence, the action set of the buyer is $\{0,1,1|Z\}$ in Table 1. The seller could either choose to execute outcome Y , Z , or Z conditional on receiving one ticket from the buyer (action $Z|1$). Hence, the action set of the seller is $\{Y,Z,Z|1\}$ in Table 1. These choices were made independently, 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).⁵ Before making a choice, subjects received some information about the opponent’s ticket holdings. The seller was told whether the buyer had either no or some ticket(s); the buyer saw whether the seller had either two or less than two tickets. No subject could hold more than 2 tickets.

As seen above, the strategy sets include a conditional action, in addition to unconditional actions. The seller (red) can choose to implement outcome Z conditional upon receipt of a ticket. The buyer (blue) can choose to transfer one ticket conditional upon Z being implemented. If subjects attach value to tickets, then conditional actions facilitate

⁵ Other conditional choices were not considered either because they are redundant (e.g., offer Y in exchange for nothing, or offer nothing in exchange for Y), or to minimize subjects' confusion (e.g., offer Z in exchange for nothing, or offer a ticket in exchange for Y). In addition, as it will be explained later, when ticket transfer is unfeasible, at least one subject in the pair has a restricted choice set. A buyer with 0 tickets had no action to take. A seller with two tickets could either choose to execute outcome Y or Z . Because only the outcome was observed, not the action, subjects could not signal by requesting or offering a ticket.

coordination in the stage game on the outcome where there is cooperation Z 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 matched agents make simultaneous proposals and only compatible proposals are implemented. Incompatible proposals lead to autarky (Kocherlakota, 1998). This requires the availability of conditional actions. Our design captures this key theoretical aspect without favoring the emergence of monetary exchange. Our 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 .

		Action of buyer (Blue)			
		0	1	1 Z	No action
Action of Seller (Red)	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: Outcome Y gives 8 points to both red and blue; outcome Z gives 20 points to Blue and 2 to Red. Ticket transfer or possession generates neither earnings nor losses. The outcomes in the Baseline treatment are in the shaded area. The last column includes all outcomes when blue has no tickets. The first two lines include all outcomes when red has two tickets.

For tractability reasons, some constraints on ticket transfers had to be imposed. On the one hand, a subject could not borrow (short sell) tickets—a standard assumption in monetary models. On the other hand, no subject could hold more than two tickets so that we avoided having one subject accumulating all tickets.⁶ Because each subject could hold 0, 1, or 2

⁶ Parameters in the experiment were selected so that a seller with two tickets theoretically would not wish to cooperate in exchange for one more ticket. That is, the upper bound on ticket holdings is not binding in monetary equilibrium. However, to simplify matters subjects in the experiment were not presented with this choice.

tickets, ticket transfers cannot take place in every circumstance. A ticket transfer is *feasible* when blue has 1 or 2 tickets and her red opponent has 0 or 1 tickets. A transfer is *unfeasible* either when blue has 0 tickets or when red has 2 tickets. Table 2 reports all possible outcomes for the Tickets treatment, for the case when ticket transfers are feasible and unfeasible. An outcome is a pair x, y where $x=Y, Z$ and $y=Transfer, No Transfer$.

The three institutions considered can generate a form of public memory while maintaining anonymity in interaction. In the IR treatment a record exists that contains a summary of the opponent's actions in the last six periods. This record can be accessed at a personal cost by a seller and so is a private good. In the IP treatment, instead, the record can be *endogenously* generated if buyers report the opponent's action at a personal cost. Here information is a public good because it is freely available to everyone. Exchange of intrinsically worthless tickets also offers a form of public memory; ticket holdings signal a subjects' frequency of cooperation.

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. Details about the number and length of sessions are provided in Table 1 (each session had 20 participants and 5 cycles).

3. Theoretical predictions

The main goal of this section is to prove that the efficient outcome can be sustained as an equilibrium in each treatment. This section is not intended to provide a full characterization of the equilibrium set. The theoretical analysis is based on the assumption of identical players, who are self-regarding and risk-neutral.

In the one-shot gift-giving game the dominant strategy for the seller is to defect, Y . The indefinite repetition of the gift-giving game with randomly selected opponents can expand the set of equilibrium outcomes. Following the work in Kandori (1992) and Ellison (1994), here

we present sufficient conditions so that the equilibrium set includes the efficient outcome. The payoff in the repeated game is the (ex-ante) expected discounted stream of payoffs in the gift-giving games.

For clarity we first present the theoretical predictions for baseline treatment. Building upon these insights, we then present predictions for the additional treatments. The baseline treatment 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 inefficient outcome can be supported as a sequential equilibrium using the strategy “defect forever.” Clearly, Y is a best response to all sellers playing Y in every period. In this case the payoff in the indefinitely repeated game is the expected discounted value of autarky forever, $a/(1-\delta)$.

If δ is sufficiently high, however, then the efficient outcome can be sustained as a sequential equilibrium. Conjecture that players behave according to actions prescribed by a social norm; a social norm is simply a rule of behavior that identifies “desirable” play and a sanction to be selected if a departure from the desirable action is observed. For a seller, we identify the desirable action by Z and the sanction by Y . We introduce the following strategy.

Definition 1 (grim trigger strategy). *Every seller cooperates as long as she has never experienced an outcome Y , and otherwise defects forever after.*

This strategy allows subjects to police deviations in a decentralized manner because any subject who experiences outcome Y in a match (as a buyer or a seller) will trigger permanent autarky. Formally, we have the following result.

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

The proof is in the appendix and follows that found in Kandori (1992). Here, we provide intuition. Remember that outcome payoffs for (seller, buyer) are (u, d) in cooperation and (a, a) in autarky. Given the social norm described above (grim trigger), on the equilibrium path

every seller cooperates so the (ex-ante) payoffs for everyone is the expected discounted utility from either consuming or producing with equal probability, $(u+d)/[2(1-\delta)]$. However, a seller might want to defect in order to earn $a>d$. Hence, since $a<(u+d)/2$ is assumed, it must be the threat of autarky forever that deters a seller from defecting. A seller deviates in several instances—first, in equilibrium, if she has not observed play of Y in the past but chooses Y currently, and second, off-equilibrium, if she has observed play of Y in the past but chooses Z currently.

Consider one-time deviations by a single seller. It should be clear that 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 today by defecting (unimprovability criterion). Instead, if autarky occurs and everyone uses a grim trigger, then everyone eventually ends up in autarky since the initial defection will spread by contagion. Given that the economy has only four players, this contagion to full autarky in our experimental economies can occur very quickly.

Cooperating after observing autarky should also be suboptimal. Choosing Z in this instance can delay the contagion, but cannot stop it. To see why, suppose a player observes Y . In the next period if he is a seller, then choosing Z yields a current loss to the player because he earns d instead of a . Hence, the player must be sufficiently impatient to prefer play of Y to 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 .⁷

The above insights lead to Proposition 2, which applies to all treatments.

Proposition 2. *In all treatments the equilibrium set includes permanent autarky and the efficient outcome.*

Proposition 2 follows directly from Proposition 1 because the grim trigger strategy is available in all treatments. This strategy can sustain the efficient outcome as a sequential equilibrium. For the efficient outcome to be an equilibrium, we need

⁷ Note that, due to private monitoring, a T-periods punishment strategy cannot support the efficient outcome as an equilibrium. 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.

$\delta > \delta_L = 0.808$ and $\delta < \delta_H = 1$. In our experimental design $\delta = 0.93$. Permanent autarky is an outcome because, as seen before, autarky is always a best response to play of autarky by the opponent.

We now discuss the specificities of the Tickets treatment. Later in the section we will discuss the Information Provision and the Information Request treatments. The Ticket treatment makes available a new strategy.

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

The modifier “fiat” emphasizes that tickets are intrinsically useless, i.e. they cannot be redeemed for points. A 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*. 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. 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. Unconditional strategies expose the subject 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. For this reason, in monetary theory exchange is based on a *quid pro quo* conditional strategy.

Our design exhibits another typical feature of monetary exchange.

Definition 3 (feasibility of monetary exchange). *We say that 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, hence a ticket transfer is unfeasible. With random selection of seller and buyer roles, there is a strictly positive 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. To sum up, if ticket transfer is feasible, then monetary exchange is possible. If ticket transfer is unfeasible, then the seller chooses autarky, Y , in that period. The use of conditional strategies $Z|1$ for the seller and $1|Z$ for the buyer achieves this outcome. Thus, with the above conditional strategy, autarky is the outcome when ticket exchange is unfeasible as well as if there is a deviation.

Proposition 3. *In the Tickets treatment, the cooperation level realized when everyone follows the monetary exchange strategy is above 0% but strictly below 100%. In the long-run, monetary exchange is feasible in 57.1% of matches, hence the monetary exchange strategy is associated to an efficiency loss of 42.8%.*

The proof of Proposition 3 is in the Appendix. To understand this result one must recognize that in our economies of four agents and four tickets there can be three possible distributions of tickets: (2,2,0,0), (2,1,1,0) and (1,1,1,1). Each of these distributions corresponds to a state of the economy that has implications for the fraction of matches in which ticket exchange is feasible. The transition from state to state depends on the random matching process, the random shocks (buyer/seller) as well as subjects' choices. The result in Proposition 3 is obtained by first calculating the unconditional (long-run) probability distribution of aggregate states, and then the associated long-run fraction of matches in which monetary exchange is feasible.

The use of the monetary exchange strategy induces an efficiency loss in the economy because ticket exchange is unfeasible in some matches. In those matches 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 (Proposition 2). In the Tickets treatment, the economy can achieve full efficiency if all subjects employ the grim trigger strategy (Proposition 2). Adoption of the monetary exchange strategy sustains only outcomes that are not fully

efficient (Proposition 3).⁸

We now turn to the specificities of the Information Provision and the Information Request treatment. Similarly to the tickets, these institutions are not essential.

Proposition 4. *Information Provision and Information Request make it possible for sellers to have accurate action histories (records) of current opponents. In the Tickets treatment accurate action histories of opponents are not available.*

In Information Request, accurate action histories always exist for the last 6 periods and a subject who is a seller can always view his opponent's record. In Information Provision, accurate records do not exist but can be created when subjects who are buyers report the action of their opponent. In the Tickets treatment, ticket holdings offer only an inaccurate record of the opponent's recent history of actions. Because of the randomness in matches and in the seller/buyer roles, holding no tickets may be the result of different histories. For instance the agent could have been a buyer twice in a row or a seller who repeatedly refused to cooperate. Hence, even when everyone adopts a monetary exchange strategy, ticket holdings provide a relatively inaccurate record for a subject. Adding tickets or removing bounds on holdings does not solve the basic problem in relative accuracies of record-keeping institutions.

Proposition 5. *In the Information Provision and Information Request treatments, the long-run efficiency loss from creating and viewing the opponents' records is no greater than 16.7%. Any strategy involving the active provision and request of information can only support equilibria that are not fully efficient.*

The key aspect of these record-keeping institutions is the endogeneity of information. The use of either information provision or request generates a deadweight loss, which lowers the

⁸ Proposition 3 is not a statement about existence of monetary equilibrium. In the Appendix we prove that monetary 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 weakly prefer to implement cooperation, Z , in exchange for one more 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. In the Appendix we also show that the constraint on holding at most 2 tickets is not binding.

efficiency frontier at any cooperation level achieved. Hence, any such strategy is inconsistent with efficiency. The maximum efficiency 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.⁹

To sum up, none of the three institutions can expand the efficiency frontier relative to the baseline treatment. In fact, the *active* use of any of these institutions lowers the efficiency frontier. However, since a multiplicity of equilibria is possible, it is an open question whether any of these institutions helps subjects to reach higher cooperation than in the private monitoring baseline case. Indeed, given that subjects cannot communicate prior to and during the game, then institutions may facilitate both the selection of high-payoff equilibria as well as the coordination on strategies that support those equilibria.

4. Results

There are five main results. Unless otherwise noted, in the empirical analysis the unit of observation is an economy, i.e. four subjects interacting in a cycle. There are 50 observations per treatment.

Result 1. *In the baseline treatment, the cooperation rate was 48.2%.*

Tables 3-4 and Figure 1 provide support for Result 1. When averaging across all periods, the rate of cooperation was 48.2% and it was 51.0% when considering only period 1 of each cycle. In addition, 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. Moreover, only 4% of economies coordinated on full cooperation, i.e., every seller always cooperated in each period of a cycle. Only 2% of economies coordinated on autarky.

⁹ 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. Studying the optimal strategy for providing and requesting information is inconsequential for Proposition 5.

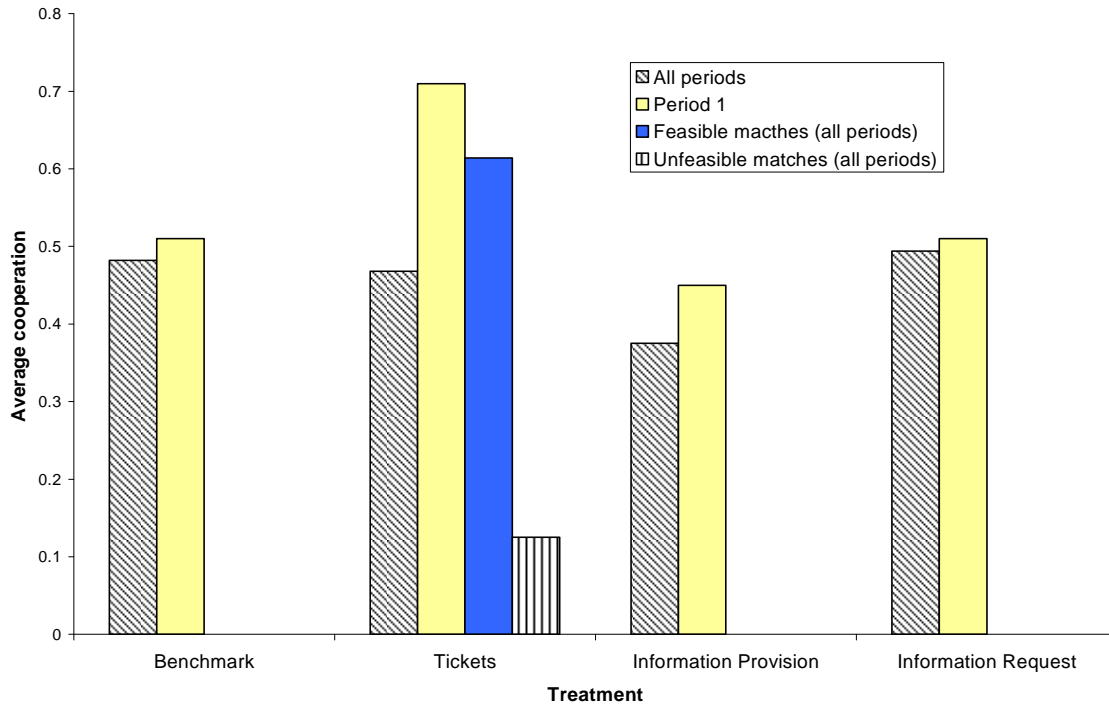


Figure 1. Cooperation by treatment

Cycle	Treatment					
	Baseline	Tickets			IP	IR
		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	--	--	4.50	5.93
Gross surplus (points)	5.78	7.53	--	--	4.99	6.17
Maximum theoretical surplus	12	12	--	--	12	12

Table 3: Average cooperation frequency: all periods

Notes to Table 3: 1 obs. = 1 economy (10 obs. per cycle, per treatment). Consider an economy $k=1, \dots, 50$. The mean cooperation level for an economy $k=1, \dots, n$ 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 $t=1,\dots,T^k$ 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 $c_k = \frac{1}{2T^k} \sum_{t=1}^{T^k} \sum_{i=1}^2 a_{it}^k$ between zero and one, and across economies is $c = \frac{1}{n} \sum_{k=1}^n c_k$. 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.

	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 full cooperation	0.30	0.58	0.10	0.24
Fraction of economies with full defection	0.28	0.16	0.20	0.22

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

Table 5 reports the results from a probit regression that explains the seller's choice to cooperate (1) or not (0) using two groups of regressors (column 3). Results are consistent with the representative subject employing a grim trigger strategy. The regression includes the subject's choices only in those periods in which she is a seller. First, 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. Second, we include a set of regressors used to trace the response of the representative subject as 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. Of course, there are several ways to choose regressors in order to trace strategies. The specification selected has the advantage to detect whether subjects followed theoretically well-known strategies, such as grim trigger (Kandori, 1992) or tit-for-tat (Axelrod, 1984). We include a

“grim trigger” regressor, which has a value of 1 in *all* periods following the first match in which *Y* was the outcome, and a value of 0 otherwise. We also include “Lag” regressors, which consider only the periods—after suffering a defection *Y*—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.¹⁰

Dependent variable: 1=cooperation 0=defection	All Treatments		Baseline	Tickets		IP	IR
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Periods 1 only			Feasible matches only			
<i>Treatment dummies:</i>							
Ticket	0.238*** (0.052)	-0.017 (0.022)					
IP	-0.048 (0.040)	-0.107*** (0.040)					
IR	0.010 (0.104)	0.006 (0.034)					
Duration of previous cycle	0.006** (0.003)	0.003*** (0.000)	-0.000 (0.008)	0.004*** (0.000)	0.005*** (0.000)	-0.003*** (0.001)	0.002*** (0.000)
<i>Cycle dummies:</i>							
Cycle 2	0.142 (0.111)	-0.032 (0.052)	0.028 (0.134)	-0.194*** (0.011)	-0.197*** (0.074)	-0.092*** (0.028)	0.113*** (0.000)
Cycle 3	0.237** (0.119)	-0.046 (0.037)	0.117 (0.117)	-0.165*** (0.054)	-0.144 (0.183)	-0.080*** (0.006)	0.077*** (0.014)
Cycle 4	0.221** (0.094)	-0.007 (0.037)	0.089 (0.158)	-0.163*** (0.003)	-0.159* (0.093)	-0.101 (0.088)	0.120*** (0.017)
Cycle 5	0.309*** (0.070)	-0.134*** (0.034)	-0.021 (0.054)	-0.238*** (0.050)	-0.144** (0.059)	-0.217*** (0.004)	-0.016 (0.036)
<i>Strategy coding:</i>							
grim trigger		-0.443*** (0.060)	-0.416*** (0.045)	-0.286*** (0.080)	-0.155** (0.068)	-0.229*** (0.009)	-0.535*** (0.042)
Lag 1		0.065** (0.033)	0.102 (0.115)	0.075* (0.039)	0.023 (0.033)	0.036*** (0.011)	0.005 (0.073)

¹⁰ There is mixed evidence on the role of the subject's major. Table 5 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.

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 (questionnaire)	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 (questionnaire)	-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)	
<i>Subject's public record shows:</i>						
at least one cooperative action					0.239***	
					(0.003)	
at least one defection action					-0.135***	
					(0.003)	
<i>Opponent's public record shows:</i>						
at least one cooperative action					0.157***	
					(0.010)	
at least one defection action					-0.096**	
					(0.045)	
Reported cooperation rate above 50% ¹¹						0.415***
						(0.024)
Reported defection rate above 50% ¹²						-0.020
						(0.102)

¹¹ This dummy variable takes value 1 when the subject asked for feedback information on her opponent, the opponent has been red 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 red.

¹² This dummy variable takes value 1 when the subject asked for feedback information on her opponent, the opponent has been red 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 red.

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 5: Probit regression on individual choice to cooperate – marginal effects

*Notes to Table 5: 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.*

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 example, if the subjects punished by choosing *Y* just at the first occurrence following 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 a tit-for-tat strategy. Moreover, the grim trigger marginal effect estimate of -0.36 is significantly different than zero at a 1 percent level, while all other strategy marginal effects are not significant (Table 5). These results are evidence of a sizable and persistent (informal) punishment behavior by the representative subject following an autarky outcome.¹³

Result 2. *In the Tickets treatment, the average cooperation rate was 61.4% when ticket exchange was feasible and 12.5% when it was unfeasible.*

The support for these results is provided in Tables 3-6. The difference in cooperation rates when ticket exchange was feasible or unfeasible is significant (Wilcoxon signed-rank test, *p*-

¹³ Another interesting result is that men cooperated more than women. The probit regression in Table 5 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. Eckel and Grossman, 2008, Ortmann and Tichy, 1999).

values 0.0000, $n=43$; 7 economies are dropped because all matches were feasible).¹⁴ In the Tickets treatment, average cooperation across all periods was 46.8%. Although this aggregate figure is not significantly different from the baseline treatment (Mann-Whitney test, p-values 0.78, $n_1=50$, $n_2=50$; Table 3), the average period 1 cooperation of 71.0% is statistically higher than in the baseline (Mann-Whitney test, p-values 0.008, $n_1=50$, $n_2=50$; Table 4). This result is also confirmed by the probit regression (Table 5, col. 1).

As explained in the theory section, our design included explicit obstacles for the exchange of tickets. On average, in economy ticket exchange was unfeasible in 32.7% of matches (Table 6). Sellers in the experiment held 2 tickets with a frequency of 21.3%, which makes them unable to accept other tickets. Buyers held no tickets with a frequency of 21.7%, which makes them unable to engage in monetary exchange. Table 6 also shows that the distribution of ticket holdings in the data is consistent with theoretical predictions.¹⁵

Buyers	Sellers			Total
	0 tickets	1 ticket	2 tickets	
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 6: Empirical distribution of ticket holdings in the average economy

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

¹⁴ The results of the statistical tests in the paper rely on the assumption that all observations are independent.

¹⁵ 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 displays, 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 6), monetary exchange is a theoretical equilibrium. In particular, one has to verify that, given homogenous risk-neutral subjects who play a monetary exchange strategy, sellers who already have one ticket weakly prefer choosing Z in exchange for a ticket, instead of choosing Y . This implies the probability of continuation of the cycle must be sufficiently high. Such a condition is satisfied for the parameterization chosen. See the proof in the Appendix.

If all subjects employ the monetary exchange strategy, then we expect an efficiency loss because ticket exchange is not always feasible. If cooperation does not take place in a match, then the surplus loss is 6 points. We adjust the realized surplus using the additional frequency of cooperation observed when ticket exchange is feasible (i.e., 61.4% minus 12.5%). The adjustment yields an empirical loss of 2.93 points in each match where ticket exchange is unfeasible. The total efficiency loss was about 0.96 points out of 6 in the average match, which is obtained considering that ticket exchange was unfeasible in 32.7% of matches (Table 6).

As we will see in the next Result, the low overall cooperation rate in the Tickets treatment may be due more to the obstacles to exchange tickets built into the design than to subjects' unwillingness to employ a monetary exchange strategy.

Result 3. *Monetary exchange greatly facilitated cooperation. On average, in an economy if ticket exchange was feasible, then a cooperative outcome was associated to the transfer of a ticket in 99.8% of cases as opposed to 7.8% of cases when autarky was the outcome.*

In the Tickets treatment, there was a ticket transfer in 43.3% of matches (67.5% when restricting to matches where ticket transfer was feasible). Subjects exchanged on average 0.87 tickets per period and 1.44 when considering only periods 1.¹⁶ We will show that the transfer of tickets was instrumental to achieve cooperation, even if full cooperation could be supported without ticket exchange (Proposition 2). That is to say, tickets are not theoretically essential in this setting.

There is overwhelming evidence that subjects adopted *conditional* monetary exchange strategies and rarely used unconditional strategies. On the one hand, buyers were not willing to give a ticket unless they were compensated with a cooperative outcome Z. On the other hand, sellers were not willing to cooperate unless they received a ticket. This evidence suggests that subjects attributed value to intrinsically worthless tickets. Table 7 provides evidence. A ticket was transferred and cooperation was the outcome in 61.2% of matches. In those matches, both subjects in a pair used conditional strategies in 83.3% of cases, while

¹⁶ 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.

both used unconditional strategies only in 0.3% of cases.

Buyers	Sellers			Total
	Y (defect)	Z (cooperate)	Z 1 (conditional)	
No action available:				
feasible	--	--	--	--
unfeasible	51.6	7.0	7.7	66.3
0 (no transfer)				
feasible	2.3	0.1	3.5	5.9
unfeasible	12.7	2.9	0.0	15.6
1 (transfer):				
feasible	2.2	0.2	1.9	4.3
unfeasible	1.6	0.3	0.0	1.9
1 Z (conditional):				
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 7: 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 matches where there is a cooperative outcome.

Why do 'worthless' tickets have a positive value in exchange against cooperation? The use of the monetary exchange strategy greatly facilitated coordination on cooperation. Figure 2 plots the frequency of ticket exchange in a match versus the frequency of a cooperative outcome at the participants' level. Figure 2 includes all matches, which implies that the frequency of monetary exchange should rarely reach 100%. The data show that the higher frequency of ticket exchange the higher the cooperation rate. The probit regression in Table 5 confirms a high and significant effect of ticket exchange on cooperative outcomes (Cols. 4-5).

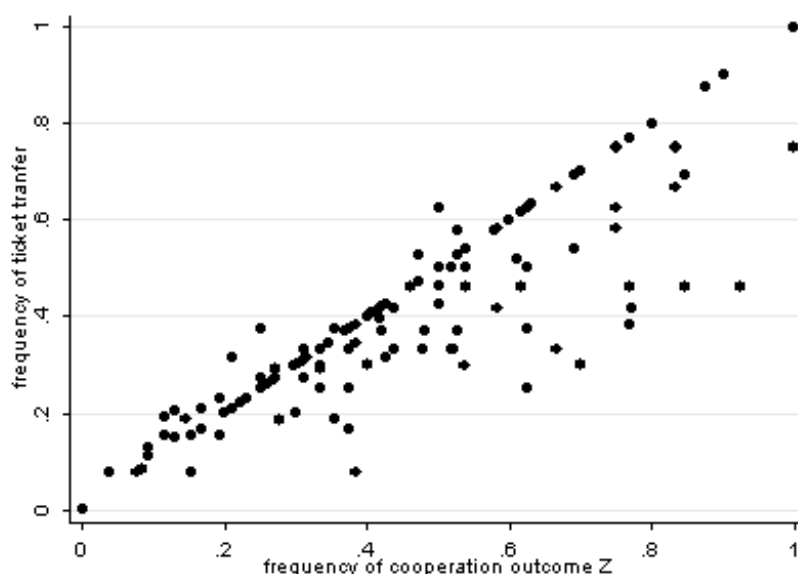


Figure 2.

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.

Monetary exchange reduces strategic risk by making cooperation *quid pro quo*. If holding a ticket is statistical evidence of being a cooperator, then subjects can cooperate only in exchange for a ticket. Tickets become a coordination device to separate subjects into two groups: those who want to cooperate, and do so by exchanging cooperation for tickets, and those who do not want to cooperate. Consistent with this interpretation, the data show a reduction in strategic risk and a redistribution of surplus from frequent defectors to frequent cooperators. Evidence of lower strategic uncertainty is a higher predictability of actions. We obtain such empirical evidence through a probit regression along the lines of Table 5 where we drop demographic independent variables that subjects could not observe (subjects were engaged in an anonymous interaction) and control for individual characteristics (Table C1 in Appendix C). The pseudo-r² statistic for the Tickets treatment is 47.9%, which increases to 65.9% when considering only matches where ticket exchange was feasible. In contrast, the baseline treatment scores 5.6% and no other treatment is above 16.3%.

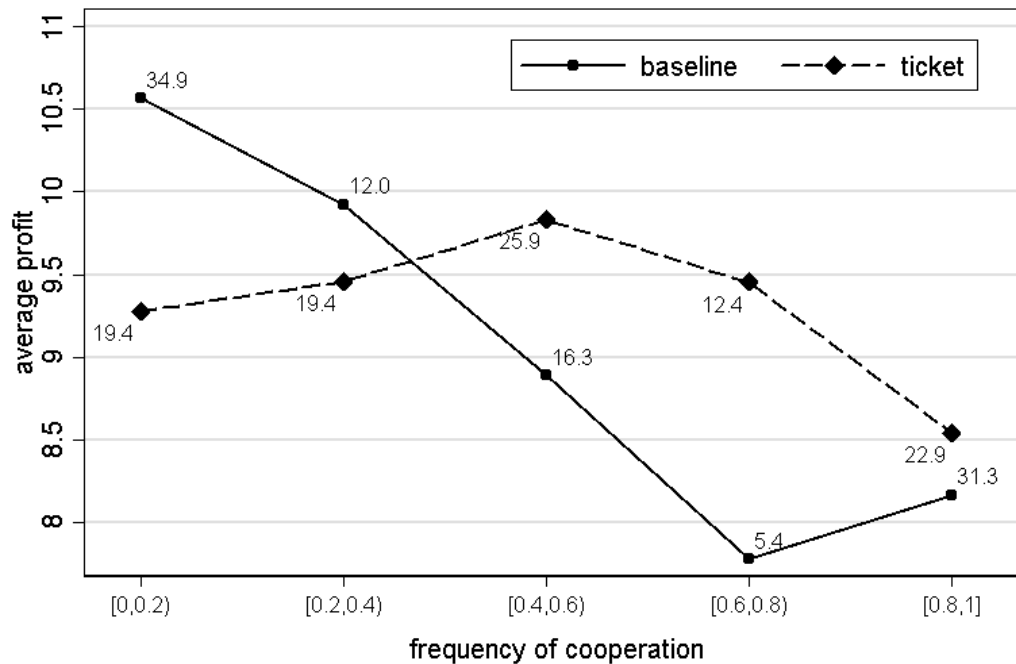


Figure 3. Cooperation rates and earnings

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. Next to each data point, we report the associated percentage of observations.

In addition, Figure 3 illustrates how the availability of tickets changes the distribution of earnings. In comparison to the Baseline treatment, subjects who cooperated less than 40% as sellers earned significantly less (Mann-Whitney tests, $p\text{-value}=0.003$, $N_1=78$, $N_2=66$). On the other hand, subjects who cooperated 40% or more earned significantly more ($p\text{-value}=0.001$, $N_1=88$, $N_2=104$).¹⁷

In sum, there is evidence that tickets in the experiment served the role of fiat money, an intrinsically useless object to which individuals attributed value because it facilitated the intertemporal giving and receiving of cooperation. Put differently, subjects in the experimental economies self-insured against future cooperation needs by holding tickets.

If subjects do indeed value tickets, then why were tickets not exchanged in all matches where doing so was possible? One can think of two possible reasons. Some subjects may have

¹⁷ Earnings were adjusted to account for the uneven frequency of a subject's role. Figure 4 does not qualitatively change when using row average profits.

not coordinated on a strategy of monetary exchange. Second, there are wealth effects that lower the incentive to implement Z . If subjects attach value to holding tickets, then the marginal value of the second ticket is less than the first. This is a standard theoretical result in monetary economics (Camera and Corbae, 1999).¹⁸ As a consequence, the incentive to cooperate is lower for sellers who already have one ticket than for those who have none. This diminished incentive for ticket-wealthy sellers may translate into lower cooperation rates, which we find in the data (Figure 4). In the experiment, sellers with 1 ticket cooperated substantially less than sellers with no tickets (69.8% vs. 49.0% in feasible matches; 67.4% vs. 43.0% in all matches).

In conclusion, the data exhibit patterns of behavior coherent with the typical description of an economy in a monetary model: trade was based on a *quid pro quo* exchange of cooperation for tickets, there was a non-degenerate distribution of ticket holdings in the economy, tickets had a decreasing marginal value.

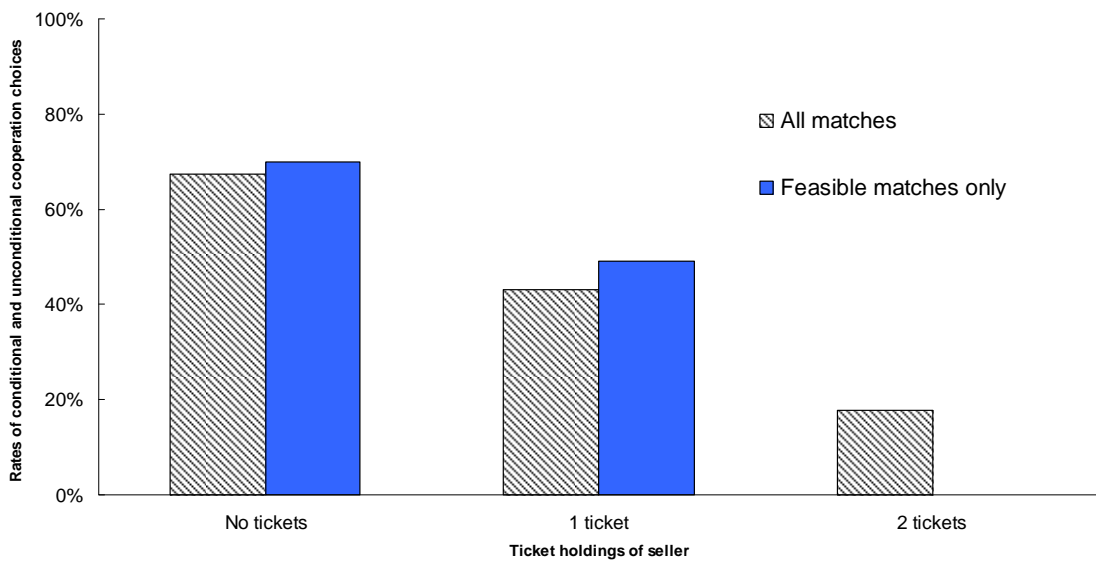


Figure 4. Cooperation rates by seller’s ticket holdings

Notes: $N=1930, 1151$; 1 obs.=seller’s choice in a period

¹⁸ 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.

Result 4. *The average cooperation rate was 37.5% in the Information Provision treatment and 49.4% in the Information Request treatment. These figures are not significantly higher than in the Baseline or the Tickets treatment.*

Support for this result is provided in Tables 3-6. Average cooperation in the IP treatment was 37.5%, which is at least 9.3 percentage points 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 percentage point 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). The above results are confirmed when we focus on the average period 1 cooperation (Table 4).¹⁹ The highest period 1 cooperation is at 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, 0.004 IR, n1=50, n2=50). These results are interesting because introducing the possibility of record-keeping does not shrink the set of discount factors that supports the efficient equilibrium. Hence, this evidence suggests an equilibrium-selection role of different record-keeping institutions.

We now study how subjects modified strategies in response to the possibility of accessing the history of actions of the opponent. If knowing the past behavior of an opponent is the key to raising cooperation levels in anonymous economies, then one would expect an extensive use of the record-keeping institution available. In the IP treatment, buyers paid 1 point to report the seller's choice in 24.5% of instances, on average. In the IR treatment, sellers paid 1 point to view the record of their buyer in 12.1% of cases, on average.

Given that subjects actively provided and requested information, it is interesting to study patterns of information manipulation and access to information in order to understand how information is used. In both treatments there is evidence that the actions of the representative subject were significantly affected by their own and their opponent's records (Table 5). The probit regressions show that a seller was significantly more willing to cooperate if their opponent cooperated in the past (Table 5, cols. 6-7). This behavior is consistent with positive

¹⁹ 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).

indirect reciprocity. In addition, in the IP treatment sellers were significantly less willing to cooperate with opponents who defected at least once. Moreover, in the IP treatment sellers' choices were significantly affected by their own record.

The patterns of information provision denote the use of informationally inefficient strategies. In the IP treatment, a subject would gain from coordinating on reporting either cooperative actions or autarky actions, but not both. In particular, given a goal to sustain cooperation, reporting only autarky actions is the less costly strategy. Instead, buyers sometimes reported cooperation and sometimes reported autarky. When considering an individual choice in a period one observation (N=1370), cooperation was reported in 33.1% of cases and autarky in 16.0% of cases. In sum, there is evidence that Information Provision and Information Request, which can reduce informational frictions, are ineffective in increasing cooperation relative to the baseline.

Result 5. *Tickets had the highest cost of use among all institutions considered. Tickets were not valued as a record-keeping device as much as a coordination device.*

The use of the Information Provision, Information Request, and Ticket institutions generated endogenous resource costs. All three institutions were used, when available, and the resulting costs were, 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. We proceed similarly to study the IP treatment.

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 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).

Why do subjects actively use these costly institutions? We identified three functions for institutions. First, institutions may expand the efficiency frontier. This function is absent in

our design. Second, they may behaviorally improve subjects' coordination on the cooperative outcome. Adding any of these institutions to the Baseline treatment expands the strategy set and, therefore, does not necessarily facilitate coordination. Third, institutions may have a redistributive function. Therefore, even if some institution has no impact on the frequency of cooperation, it may be still desirable from an individual perspective. For example, it can reduce the strategic risk of cooperation or it can promote the pursuit of other-regarding motives.

As ticket exchange is the most costly institution to use in our design, its use may serve purposes that are not satisfied by IP and IR. There are several possible purposes. First, monetary theory links the value of money to its ability to expand the efficiency frontier. The Tickets treatment does not satisfy this requirement: in our economies not only the efficient equilibrium can be reached without tickets, but monetary exchange is, inconsistent with efficiency. Second, monetary theory also suggests that the value of fiat money is linked to its record-keeping role (Ostroy and Starr, 1990). The experimental design implemented allows studying empirically whether this is the case. Note that all three institutions in our design provide various degrees of record-keeping, at different costs. The IR and IP institution can generate an accurate record of the opponent's actions, which is publicly accessible. In the IR treatment if every seller always views the buyer's record, then the cost is 16.7% of total surplus. The same is true in the IP treatment when every buyer reports the seller's action. Tickets cannot generate an accurate record of the opponent's actions and are associated to the largest cost, both theoretically and empirically (Proposition 3, actual cost was 15.9%). If knowledge of past behaviors is the key to coordinate on cooperation, then the IR and IP institutions should generate a larger, favorable impact on cooperation. Such institutions supply better information than tickets and they do so at a lower cost. As the data do not support this interpretation, we need to search for a different reason for monetary exchange.

Third, the use of tickets can allow strategies based on reciprocity. Given the anonymity and private monitoring of our design, only indirect reciprocity is available. The literature has identified indirect reciprocity as one important mechanism behind cooperation (e.g. see the survey in Fehr and Gaechter, 2000). The experimental design implemented allows discerning whether indirect reciprocity plays a key role. Strategies based on indirect reciprocity are more

selective in punishment than a 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 only cooperate in return for a ticket. The evidence suggests indirect reciprocity is not what drives ticket exchange. Notice that sellers' cooperation rates should be invariant to *their* ticket holdings. However, in the data, sellers' cooperation rates declined in their ticket holdings (Figure 4), which is evidence of forward looking behavior and not of indirectly reciprocal, backward-looking behavior. Moreover, the data show that sellers lowered their cooperation rates when they could not acquire a third ticket, even if the buyer had one (the cooperation rate was 19.0% if the buyer had one or two tickets and 16.7% otherwise).

To sum up, in the experiment the use of tickets cannot expand the efficiency frontier, is not explained by indirect reciprocity, and does not fulfill record-keeping needs. Ticket exchange seems to be valued for its behavioral role in improving coordination on cooperation.

A possible reason for this coordination role of ticket exchange is the following. Decentralized enforcement requires a great deal of coordination. *Everyone* in the population 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 population. For instance, a single pair of subjects can follow a monetary exchange strategy regardless of what others do. This is especially important in heterogeneous populations, where decentralized enforcement requires a high degree of coordination. This difference emerges in the comparison between Information Request and Information Provision. With IR, information on past actions is always available, and must be only purchased. Hence, a subset of subjects may coordinate on history-dependent strategies, while

others may choose to rely on an anonymous grim trigger strategy. For example, some subjects may choose to cooperate only with those subjects whose record shows that they have always cooperated in the past. 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.

6. Discussion and Conclusions

This study uncovered a new behavioral foundation for the use of fiat money in promoting impersonal exchange. In our laboratory economies the exchange of intrinsically worthless tickets does not expand the efficiency frontier. Yet, ticket exchange 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, strangers interact locally and are involved in an indefinite sequence of bilateral encounters where they can either give or receive a good. There exist gains from inter-temporal cooperation because a seller can transfer a good to a buyer who values it more (a gift-giving game). In these economies there is no possibility to rely on direct reciprocity or engage in relational contracts because subjects are anonymous and cannot communicate.

This study has focused on three institutions that supplied different record-keeping technologies. In *Information Provision*, subjects could contribute to create, at a personal cost, an accurate public record of their opponent's history of actions. In *Information Request*, subjects could purchase the opponent's accurate record of actions. In *Tickets*, subjects could hold and exchange intrinsically worthless electronic objects, which resemble fiat money. None of these institutions is *theoretically* essential to sustain the efficient outcome (Proposition 2), which can be achieved in all treatments through decentralized enforcement (Kandori, 1992).

Information Provision and Request can supply a more accurate record of the opponent's history than Tickets, and at a lower cost. Yet, they did not appreciably lead to higher cooperation.²⁰ Hence the accuracy of the record-keeping technology available does not seem to be the key to successful cooperation.

²⁰ More information was generated when records of actions were a private good (Information Request) than when they were a voluntarily provided public good (Information Provision).

A main result is that monetary exchange greatly facilitated coordination on cooperation. Ticket economies achieved the highest cooperation in period 1 and, overall, the highest gross surplus; subjects who most frequently engaged in ticket exchange experienced the highest cooperation rates. These results are remarkable because in the experiment the efficient outcome cannot be reached by a monetary exchange strategy but it can be reached without exchanging tickets (folk theorems). There are limitations to monetary exchange because it is not feasible when the buyer has no money, and is not optimal when the marginal value of money for the seller is too low. This feature is the standard source of inefficiency in distributional models of monetary exchange (e.g., Camera and Corbae, 1999). Therefore to interpret the experimental results, one has to focus on interactions when the exchange of tickets was feasible (Definition 3).

When ticket exchange was feasible, a cooperative outcome was associated to the transfer of a ticket in 99.7% of cases (Result 3). The average cooperation rate when ticket exchange was feasible was significantly higher than in the baseline treatment (Results 1-2). 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, there was a non-degenerate distribution of ticket holdings in the economy, and there is evidence that tickets had a decreasing marginal value.

Decentralized enforcement requires a great deal of coordination because subjects have many outcomes and strategies to choose from. Fiat monetary exchange has a fundamental behavioral role in facilitating coordination. First, ticket exchange 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 population. For instance, a single pair of subjects can follow a monetary exchange strategy regardless of what others do. This is especially important in heterogeneous populations.²¹ Second, ticket 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

²¹ This argument also explains differences in empirical patterns between Information Provision and Information Request. When comparing IP and IR, we also observe in IR an income redistribution from low frequency cooperators to high frequency cooperators with respect to IP. See figure C2 in Appendix C.

not receive a ticket due to the *quid pro quo* nature of the monetary exchange strategy.

These patterns of coordination generated a distinctly different income distribution in the experiment (Figure 3). In comparison to the Baseline treatment, subjects who cooperated less than 40% as sellers earned significantly less. On the other hand, subjects who cooperated 40% or more earned significantly more. While there was a modest difference in aggregate earnings between Baseline and Tickets treatment, there still was a substantive motivation to adopt a monetary exchange strategy for subjects focusing on cooperation.

In conclusion, these results are interesting because money plays no role in most (macro)economic models: the basic insights from the theories of growth, asset pricing, business cycles, or unemployment, for instance, emerge from models where money plays no role. Yet, monetary exchange is a defining feature of virtually every economy. So, why is there money? In the foundations of monetary theory, money has value only if it expands the efficiency frontier: money facilitates impersonal exchange and allows transactions that would not otherwise occur because of limitations in commitment, enforcement, and punishment (Huggett and Krasa 1996, Kocherlakota, 1998). 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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Appendix A

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

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

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

$$-c + \beta V \geq a + \beta v_2. \quad (2)$$

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

$$v_4 = \frac{a}{1 - \beta} \quad (3)$$

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

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

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

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

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

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

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

$$v_2 = \frac{2}{3(2-\beta)^2} \left\{ (u + 2a)(2 - \beta) + \beta \left[\frac{(2+\beta)a}{2(1-\beta)} + \frac{u+5a}{3} \right] \right\}. \quad (7)$$

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 $\beta \rightarrow 0$ we have $V \rightarrow \frac{u-c}{2}$ and $v_2 \rightarrow \frac{u+2a}{3}$. So, clearly, as $\beta \rightarrow 0$ 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 $\beta \rightarrow 1$, we have $v_2 \rightarrow \infty$ and $V \rightarrow \infty$. It should be clear that as $\beta \rightarrow 1$ then $\frac{a+c}{v_2} \rightarrow 0$. In addition, the RHS of the inequality converges to a positive quantity since, as $\beta \rightarrow 1$, then $\frac{V}{v_2} \rightarrow \frac{u-c}{2a} > 1$, 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

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

- 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

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

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:

$$\begin{array}{l} B B S S \\ d_{1a} : 2 2 0 0 \text{ (exchange always **feasible**)} \\ d_{1b} : 2 0 2 0 \text{ (exchange **can be** unfeasible)} \\ d_{1c} : 0 0 2 2 \text{ (exchange always **unfeasible**)} \end{array}$$

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

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

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

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

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

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

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:

$$\begin{aligned} &\{(B = 1, S = 2), (B = 0, S = 1)\} \text{ (exchange always **unfeasible**)} \\ &\{(B = 1, S = 1), (B = 0, S = 2)\} \text{ (exchange **feasible** in 1 match).} \end{aligned}$$

From the discussion above, we have

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

Suppose the distribution is $d_3 = (1, 1, 1)$. 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:

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

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 .