EXPERIMENTAL EVIDENCE ON THE ESSENTIALITY AND NEUTRALITY OF MONEY IN A SEARCH MODEL

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ABSTRACT

We study a microfounded search model of exchange in the laboratory. Using a within-subjects design, we consider exchange behavior with and without an intrinsically worthless token object. While these tokens have no redemption value, like fiat money they may foster greater exchange and welfare via the coordinating role of having prices of goods in terms of tokens. We find that welfare is indeed improved by the presence of tokens provided that the economy starts out with a supply of such tokens. In economies that operate for some time without tokens, the later surprise introduction of tokens does not serve to improve welfare. We also explore the impact of announced changes in the economy-wide stock of tokens (fiat money) on prices. Consistent with the quantity theory of money, we find that increases in the stock of money (tokens) have no real effects and mainly result in proportionate changes to prices.

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However, the same finding does not hold for decreases in the stock of money.

Keywords: Money; search; gift exchange; social norms; neutrality of money; experimental economics

INTRODUCTION

The use of money in exchange is a relatively recent development in the 200,000-year history of modern humans. The earliest known use of commodity (gold) money was approximately 5,000 years ago during the Bronze age (third millennium BC) in Mesopotamia and Egypt while the earliest known use of fiat (paper) money is around 800 years ago during the Song dynasty in China.[1] Prior to the development of monetary exchange, nonmonetary "gift exchange" systems were the norm – see Graeber (2011).[2] In a gift-exchange system, there is no money object and exchanges may not be direct or immediate. For example, a landowner might provide peasants with household provisions in exchange for promises of later repayment in terms of crops at harvest time. These gift-exchange systems were governed by well-defined social norms of behavior, for example, community-wide sanctioning mechanisms, and worked well so long as the extent of the market remained limited; they eventually broke down and were replaced by monetary exchange systems and explicit collateral requirements as the extent of the market broadened, agents became more specialized and community-wide enforcement became more difficult to enforce – see Greif (2006).

The conditions under which gift and monetary exchange systems can be rationalized as equilibrium outcomes have recently become the subject of a large theoretical literature in modern monetary economics employing microfounded search-theoretic models (see Lagos, Rocheteau, & Wright, 2014; Nosal & Rocheteau, 2011 and Williamson & Wright, 2011 for surveys). These models make clear the frictions and assumptions under which gift exchange and monetary exchange systems can be rationalized as an equilibrium phenomenon. With a finite population of agents, nonmonetary gift-exchange equilibria can, in principle, be sustained under the starkest of environmental conditions, namely anonymous random matching of agents, lack of commitment or enforcement, and only decentralized information on exchange behavior, provided that members of the economy as a whole play according to a grim trigger "contagious strategy" as first suggested by Kandori (1992) and extended to the search-theoretic exchange framework by Araujo (2004). Monetary equilibria, where intrinsically worthless token objects are used as part of the exchange process, can co-exist in such environments. However, in these same environments, monetary systems cannot achieve the first best outcome whereas gift-exchange systems can. In particular, due to a time delay between the acceptance of money for production and the use of that money for later consumption, monetary equilibria will generally be less efficient than a subset of the nonmonetary gift-exchange equilibria that are possible in anonymous random matching exchange economies with finite populations of agents. Thus, in these environments, money is *not essential* in the sense that the introduction of money does not expand the Pareto frontier. Indeed, the addition of money to the nonmonetary environment we study does not affect the set of equilibria since there always exists a gift-exchange equilibrium (not involving the use of money) that implements the same equilibrium allocation as in the monetary equilibrium and results in the same welfare.

In Duffy and Puzzello (2014), we explored whether gift-exchange equilibria could indeed be welfare improving relative to monetary equilibria in a laboratory experiment implementing a version of Lagos and Wright's (2005) search-theoretic model of money. Despite the theoretical possibility that gift-exchange equilibria could achieve higher levels of welfare than the unique monetary equilibrium in the same environment, we found just the opposite: exchange activity and welfare were found to be higher when monetary exchange was possible than under a pure, nonmonetary gift-exchange system. We thus concluded that while money was not theoretically essential, behaviorally speaking money was essential to the achievement of higher welfare. We attributed that outcome to the coordinating role played by money and prices in monetary exchange systems. The experiments we reported on in that paper either had no money or a constant supply of a worthless token (fiat money) object that was present in the system at all times. In this article, we follow up on our earlier experimental study and ask whether the introduction or the removal of a token (money) object has any effect on exchange behavior and welfare. In particular, we are interested in understanding the historical transition from nonmonetary gift exchange to monetary exchange as well as the reverse scenario.

In addition to exploring the essentiality of money, we further explore whether or not announced changes in the economy-wide quantity of a token money object have purely neutral effects on real activity, resulting only in changes to prices, as would be consistent with the long-run "neutrality-of-money" proposition. This proposition has an even more recent history dating back to Hume's (1752) essay, "Of Money." As Hume (1752) observed:

> If we consider any one kingdom by itself, it is evident, that the greater or less plenty of money is of no consequence; since the prices of commodities are always proportionate to the plenty of money…

Hume's logic follows directly from the quantity theory of money. A one-time, unexpected and permanent increase in the money supply should eventually result in an adjustment in the price level only, leaving all real activity unaffected. The main difficulty with testing this proposition (outside of the laboratory) is that a one-time, unexpected and permanent increase in the money supply is not easy to engineer in a natural economic setting, and indeed, we are not aware of any such naturally occurring experiments. Nevertheless, all modern microfounded models in monetary economics involving rational agents and markets that always are clear, predict the long-run neutrality of money and so it is of interest to consider the empirical support for this proposition.

Our first new experimental treatment explores the transition from a nonmonetary exchange economy to an economy with a constant supply of fiat money and asks whether the introduction of a fiat money object results in greater exchange and welfare mirroring the transition from gift-exchange to monetary exchange that was observed in human history. We also explore the reverse transition from a monetary world to a nonmonetary world. Here our main experimental finding is that economies that start off without a token (money) object coordinate on low-welfare gift-exchange equilibria, as we previously observed in Duffy and Puzzello (2014). The surprise introduction of a token (money) object midway through the experiment, however, does not increase exchange or raise welfare; instead, exchange and welfare remain low relative to the first best even after the token object is introduced, though subjects do use the token object in exchange. By contrast, if the economy starts out with a fixed supply of the token (fiat money) object, the presence of that object in the economy results in higher amounts of exchange and higher welfare relative to economies without the token object, again consistent with the findings of Duffy and Puzzello (2014). If that token object is removed (again as a surprise) midway through the experiment, the amount of exchange drops precipitously as does the level of welfare. These findings suggest that money plays an important coordination role in raising welfare but only if the economy has not previously coordinated on low-welfare gift-exchange equilibria. In particular, our results suggest that the exchange history of an environment into which a money object is introduced is critical as to whether or not that money object is welfare-enhancing.

Our second new experimental treatment concerns a change in the stock of the token fiat money object. In particular, we place subjects in an environment with a constant total stock of M units of the fiat money object and midway through the experiment we make a surprise announcement that the supply of money is doubling to $2M$. We also explore the reverse sequence of events in which agents start out in an economy with a total stock of fiat money of $2M$ units and midway through the experiment we make a surprise announcement that the supply of money is being reduced from $2M$ to M total units. In the case where the money supply doubles from M to $2M$, we find that, consistent with the neutrality-of-money proposition, there are no real effects and prices also approximately double. However, in the reverse case where the money stock is reduced by half, prices do not decline proportionally and thus there are some real effects, in contrast to the neutrality-of-money proposition.

While the models and theory we are testing in this article are not new, the methodology of using laboratory methods to explore exchange behavior in economies with or without money and the validity of the neutrality-of-money proposition is a novel approach to evaluating these models and theories. As our research demonstrates, the key advantage of using laboratory methods is that it provides us with the control necessary to implement the dynamic, intertemporal infinite horizon search-theoretic approach to modeling monetary and nonmonetary exchange, in particular, the pairwise anonymous random matching of subjects in combination with centralized Walrasian meetings. In addition, in the laboratory, it is possible to engage in policy experiments such as doubling the money supply that would be impossible (not to mention unethical) to conduct in the real world. Further, laboratory experiments provide us with a means of checking the robustness of theoretical predictions to populations of agents that may depart from the rational choice ideal in various ways. Finally, and perhaps most importantly, the theoretical environment we study admits a multiplicity of gift-exchange equilibria, in addition to a unique monetary exchange equilibrium. The question of which equilibrium (if any) is selected is ultimately an empirical question that laboratory methods allow us to address.

The remainder of this article is organized as follows. The next section discusses related literature. The section "The Lagos-Wright Environment" describes the Lagos-Wright environment that we implement in the laboratory including the parameterization of the model and equilibrium predictions. The section "Experimental Design" presents our experimental design and the section "Experimental Results" summarizes the main findings from our experiment. Finally, the section "Conclusions and Directions for Future Research" provides a summary of the article as well as some directions for future research.

RELATED LITERATURE

The focus of this article is on the essentiality and neutrality of fiat money. Regarding the essentiality of money, the most closely related article is that by Duffy and Puzzello (2014), who also study the Lagos and Wright (2005) model of monetary exchange in the laboratory with a necessarily finite population of subjects (Lagos & Wright, 2005 have an infinite continuum).[3] Given a finite population of sufficiently patient agents, there exists a continuum of nonmonetary gift-exchange equilibria in addition to the monetary equilibrium; these gift-exchange equilibria are supported by a contagious grim-trigger strategy played by the society of agents as a whole (Kandori, 1992). Some of these gift-exchange equilibria Pareto dominate the monetary equilibrium implying that money may fail to be essential (e.g., Aliprantis, Camera, & Puzzello, 2007a, 2007b; Araujo, 2004; Araujo, Camargo, Minetti, & Puzzello, 2012). However, Duffy and Puzzello find that subjects avoid nonmonetary gift-exchange equilibria in favor of coordinating on the monetary equilibrium. Duffy and Puzzello also study versions of the model when money is not available (see Aliprantis et al., 2007a, 2007b and Araujo et al., 2012) and find that welfare is significantly higher in environments with money than without money, suggesting that money plays a key role as an efficiency enhancing coordination device.

Camera and Casari (2014) also compare outcomes across two environments, with fiat money ("tickets") and without fiat money. In their dynamic game, which shares some similarities with the Prisoner's Dilemma game, money is also not essential for achievement of the Pareto efficient outcome which can instead be supported by social norms. The monetary environment they study involves both dynamic and distributional inefficiencies associated with the first generation Kiyotaki and Wright (1989) money-search model in that ticket prices are exogenously fixed (there is no bargaining), money and goods are indivisible, there are restrictions on money holdings, and there is only decentralized pairwise random matching (there is no centralized meeting (CM) involving all players). They also consider only small groups of four subjects, which may facilitate social norm mechanisms. Indeed, they find that the introduction of money does not improve average overall cooperation rates (exchanges) relative to an environment without money.

Neither Camera and Casari (2014) nor Duffy and Puzzello (2014) explore what happens to patterns of exchange when money is first introduced and then removed, or when money is introduced at a later stage; that is, neither article employs a within-subjects design as we do in this article.

Regarding the neutrality-of-money hypothesis, our article is related to Lian and Plott (1998) who find support for the neutrality hypothesis in a general equilibrium environment using a between-subjects design. Their experiment involves a cash-in-advance constraint so that money must be used in exchange and they imbue their money object (francs) with a known redemption value, which is reminiscent of commodity-money regimes. By contrast, we consider a within-subjects design, without any cash-in-advance constraints and where the token objects that can serve as money have no redemption value, as is the case of fiat money systems.[4] Our study is also indirectly related to the experimental literature on money illusion. Shafir, Diamond, and Tversky (1997) collect *survey* data that support the conjecture that people tend to think in terms of nominal rather than real nominal values. In their study, people chose between different options presented in nominal or real terms and their reactions to variations in inflation and prices indicated the presence of money illusion. Fehr and Tyran (2001) propose an experimental approach to money illusion by studying firms' price setting behavior in a monopolistically competitive economy. They find that the presence of money illusion has implications for real allocations, especially after negative nominal shocks, that is, money is not neutral after negative shocks. Similarly, Noussair, Richter, and Tyran (2012) also find an asymmetry in price adjustments in response to inflationary or deflationary nominal shocks in experimental asset markets. Specifically, they report that prices exhibit nominal inertia after a deflationary shock. Petersen and Winn (2014) argue that the nominal inertia observed by Fehr and Tyran (2001) is mainly due to the adaptive nature of firms' best responses rather than money illusion per se, but Fehr and Tyran (2014) argue that this is too narrow an interpretation. By contrast, in this article we provide a test of the neutrality-of-money proposition in a more explicit, exchange-oriented setting, where agents must bargain over quantities and prices. In particular we study the Lagos and Wright (2005) search model of money, where money may or may not be used for exchange purposes. We find some qualified support for the neutrality-of-money proposition in response to inflationary shocks. However, consistent with the earlier experimental literature, we also find that prices do not adjust downward in response to a deflationary shock.

THE LAGOS-WRIGHT ENVIRONMENT

In this section, we describe a modified version of the Lagos and Wright (2005) model with a finite population of agents. Time is discrete and the horizon is infinite. Let the population consist of $2N$ infinitely lived agents and let $\beta \in (0,1)$ denote the discount factor.

Each period is divided into two subperiods. In the first subperiod agents interact in decentralized meetings (DMs) while in the second subperiod trade is organized via a centralized meeting (CM).

In the first subperiod agents are randomly and bilaterally matched and every agent in a pair is either a producer or a consumer of a special good in his match with equal probability. Note that this generates gains from trade since agents cannot produce for their own consumption. We denote by x and y consumption and production in the first subperiod. In the second subperiod, agents trade in a CM (Walrasian market) and every agent can produce and consume a general good. Let X and Y denote production and consumption in the second subperiod.

Preferences are given by

$$\mathcal{U}(x, y, X, Y) = u(x) - c(y) + X - Y$$

where u, and c are twice continuously differentiable with $u' > 0$, $c' > 0$, $u'' < 0$, $c'' \geq 0$. There exists a $q^* \in (0,\infty)$ such that $u'(q^*)=c'(q^*)$, that is, q^* is efficient as it maximizes the surplus in a pair. Also, let $\overline{q} > 0$ be such that $u(\overline{q}) = c(\overline{q})$.[5]

Furthermore, the goods produced during the two subperiods are perfectly divisible and nonstorable. There is another object called fiat money that is perfectly divisible and storable in any amount $m \geq 0$. We will consider two environments: one where the money supply is fixed at M and one where the money supply is twice as large and fixed at $2M$. Notice that the environment lacks commitment and formal enforcement. However, since our population is finite, in addition to the monetary equilibrium, there exist multiple nonmonetary equilibria supported by informal enforcement schemes (see Aliprantis et al., 2007a, 2007b; Araujo et al., 2012; Ellison, 1994; Kandori, 1992).

In what follows, we just report the main theoretical predictions and we refer the interested reader to Duffy and Puzzello (2014) for further details and proofs.

Monetary Equilibrium

In the Lagos-Wright model, there always exists a nonmonetary, autarkic equilibrium where money is not used and there is no exchange of goods. In addition, there exists a monetary equilibrium involving positive exchange of goods for money which we describe in this section. Let ϕ_t denote the price of money in terms of the general good in the CM. Under the assumption of a take-it-or-leave-it bargaining protocol in the DM (which we use in the experiment and where the consumer has all the bargaining power), it can be shown that the monetary steady state is unique. The amount $\tilde{q}$ of the special good exchanged for money in each DM in the steady state is pinned down by the following functional equation

$$\frac{u'(\tilde{q})}{c'(\tilde{q})} = 1 + \frac{1-\beta}{(\beta/2)} \tag{1}$$

Supposing that the aggregate supply of money is M, the equilibrium price of money in the CM in the steady state is $\phi = (c(\tilde{q}))/(M/2N)$. Prices in the DMs are given by $(M/2N)/(c(\tilde{q}))$. Furthermore, periodic access to the centralized market and quasilinearity of preferences imply that agents are able to perfectly rebalance their money holdings: the distribution of money holdings at the beginning of each DM is therefore degenerate at $M/2N$. Because of discounting ($\beta < 1$), the first best is not achieved as a monetary equilibrium, in the absence of the Friedman rule Friedman (1969).

Note that if the money supply is instead doubled to $2M$, the prices of goods in the DM and CM double but production and consumption equilibrium quantities remain unchanged, that is, money is neutral in this model. To see this more clearly, notice that Eq. (1) does not directly depend on the value of M.

Social Norms in the Lagos-Wright Environment

The model in the previous section can also be described as an infinitely repeated trading game. It is easy to see that producing zero regardless of the history of play is always an equilibrium, that is, autarky remains an equilibrium. However, there also exist nonmonetary, pure "gift-exchange" equilibria that sustain positive amounts of production and consumption (including the first-best) as sequential Nash equilibria through the use of a community-wide contagious strategy mechanism (see Araujo, 2004; Ellison, 1994; and Kandori, 1992). In order to describe these equilibria, we assume that consumers propose terms of trade so that their action set is given by $[0, \overline{q}] \times [0, \overline{M}]$.[6] The action set of producers is identified with {0,1} where 0 stands for reject and 1 stands for accept.

Let $0 < q \leq q^*$ be some positive amount of production and consumption in the DMs. Consider a strategy that prescribes to shut down the CM and to participate only in DMs. In the latter meetings, the strategy prescribes that consumers propose (q,0) and producers accept (q,0), so long as they have always observed these proposals being accepted in past meetings. As soon as a deviation is observed, then the strategy prescribes rejection of any proposal *forever after* whenever an agent is in the producer role. As in Duffy and Puzzello (2014), we label this strategy as a *decentralized gift-giving* social norm, since it only relies on contagion being spread by means of decentralized interactions. It is possible to show that this social norm is supported as a sequential equilibrium if agents are patient enough (see Duffy & Puzzello, 2014).

The intuition behind this result is as in Kandori (1992), namely that cooperation can be supported since a single deviation by an agent implies that any agent who has observed it stops producing whenever a producer and thus, defection spreads like an epidemic that eventually hits the whole community leading to autarky. The threat of triggering such a contagious reaction can suffice to support a cooperative gift-exchange social norm of the type characterized above.

The No-Money Environment

In addition to studying the Lagos-Wright model, we also study a variant of this environment, due to Araujo et al. (2012) where there is no money. In the DMs of this environment, consumers propose quantities that producers should produce for them so that a consumer's action set is again given by $[0, \overline{q}]$. The action set of producers is again identified with {0,1} where 0 stands for reject and 1 stands for accept. Following the DM, agents can choose whether to participate in the centralized trading post for the general good. Since this is not an endowment economy, agents first choose whether to produce $0 \leq y \leq \overline{Y}$ units of the general good, where $\overline{Y}$ denotes the upper bound on production. Second, they decide how much to bid, b, for the general good with the constraint that their bid cannot exceed their production, that is, $0 \leq b \leq y$. The price of the CCM general good is determined by the ratio of the sum of bids to the sum of individual production amounts, that is, $p = \sum b_i / \sum y_i$. If $\sum b_i = 0$ or $\sum y_i = 0$, then $p = 0$ and no trade takes place. Consumption for an agent whose bid is b is determined by b/p. Since preferences are linear in the CM stage, payoffs are given by $U(b,y,p) = (b/p) - y$. Let $0 < q \leq q^*$ be a positive amount of production and consumption in DMs. The decentralized gift-giving social norm remains a sequential equilibrium of the trading game. In addition to decentralized social norms, there also exist *centralized social norms* where the trading post price in the CM can be used a signaling device. It is possible to show that if agents are sufficiently patient, positive amounts of production and consumption (including the first best) can be supported as sequential equilibria (see Duffy & Puzzello, 2014 for details). Contagion under these social norms is much faster thus implying that good allocations can be supported with lower thresholds for the discount factor than in the case of the decentralized social norms of the Lagos-Wright environment.

Parameterization and Equilibrium Benchmarks

As in most sessions of Duffy and Puzzello, we considered a population of $2N = 14$ subjects. The utility function (cost function) in the DM was given by $u(q) = A \ln(1 + q)$ $(c(q) = Cq)$. We set $A = 7$, $C = 1$, and $\beta = 5/6$, again following the choices made in our earlier paper. The aggregate supply of money was given by $M = 112$ (with an initial endowment of money per capita of $M/2N = 8$) and it remained constant in the money treatment part of sessions contrasting money with no money. In our treatments involving the neutrality-of-money proposition, we considered environments where the money supply doubled from $M = 112$ to $2M = 224$ (with an initial endowment per capita of $M/2N = 16$) or the reverse scenario where the initial supply of money was $2M = 224$ and then dropped to $M = 112$.

Given these parameter choices, the first best quantity is $q^* = 6$, while the equilibrium quantity associated with the *monetary equilibrium* is $\tilde{q} = 4$. The upper bound for the special good in the DM is $\overline{q} = 22$.[7] We also chose an upper bound of $\overline{Y} = 22$ for the CM. Regarding prices, the equilibrium price of the special good in the DM is given by $p = (M/2N)/\tilde{q} = 8/4 = 2$. The equilibrium price of money in terms of the general good in the CM is $\phi = (c(\tilde{q}))/(M/2N) = 1/2$ and so the equilibrium price of the general good in terms of money is the reciprocal $P = 2$. When M is doubled, prices are doubled but the equilibrium quantity associated with the monetary equilibrium remains $\tilde{q}=4$. Finally, for the purpose of calculating welfare, we note that the period monetary equilibrium payoff per pair is $v=\{7 \log 5-4\}=7.26$ and the period first best payoff per pair is $v^*\{7 \log 7-6\}=7.62$. Thus, the monetary equilibrium is predicted to achieve 95.3 percent of the welfare under the first best equilibrium.

Regarding *social norm equilibria*, the lowest value of the discount factors, β, for which the first best can be supported are given by $\underline{\beta}^{CM}=0.6427$ and $\underline{\beta}^{DM}=0.8256$, where the superscript refers to our focus on the centralized or decentralized, nonmonetary social norm. Our choice for $\beta=5/6$ exceeds both of these minimal threshold discount factors, so that the first best can be supported as a sequential Nash equilibrium under both types of social norms, decentralized and centralized (see Duffy & Puzzello, 2014 for more details).

In addition to the first best, lower but positive production and consumption levels, q, in the DM can also be supported as sequential, nonmonetary social norm equilibria under our parameterization of the model. Tables 1 and 2 summarize equilibrium predictions for quantities and prices under the various types of equilibria that are possible in the Lagos-Wright environment that we implemented in the laboratory.

EXPERIMENTAL DESIGN

The experiment was computerized using the z-Tree software (Fischbacher, 2007). Each session involved $2N=14$ subjects drawn from the undergraduate

Table 1. Equilibrium Predictions Regarding q.

Group Size	Decentralized Social Norm	Monetary Equilibrium	Autarkic Equilibrium
$N=14$	$0.5\leq q\leq 6$	$q=4$	$q=0$

Table 2. Equilibrium Predictions Regarding Decentralized Meeting (DM) Price p and Centralized Meeting (CM) Price p.

Per-Capita Money Holdings	Price DM P	Price CM P
$M/2N=8$	2	2
$M/2N=16$	4	4

population of the University of Pittsburgh. No subject had any prior experience with any of the treatment environments of our experiment; subjects were only allowed to participate in a single experimental session.

Our experiment involved a within-subjects design where each session had subjects participate in two distinct treatments or "parts" as they were referred to in the instructions. Prior to each treatment/part subjects were given written instructions which were read aloud in an effort to make these instructions public knowledge.[8] Subjects also had to answer comprehensive quiz questions to confirm their familiarity with the environment. Mistaken answers to quiz questions were reviewed aloud in an effort to minimize mistakes due to comprehension problems.

The experiment consists of four different, within-subject treatments each consisting of two parts. In the "NM-M" treatment, the first part of the session consisted of several indefinite sequences of the no-money (NM) environment. The second part consisted of several indefinite sequences of the money (M) environment. In the "M-NM" treatment, the two parts were reversed: the first part consisted of several indefinite sequences of M environment followed by a second part involving several indefinite sequences of the NM environment. In the "M-$2M$" treatment, the first part consisted of several indefinite sequences of the M environment (as in the M-NM treatment), while the second part consisted of several indefinite sequences of the $2M$ environment, where the only change was that the money supply was doubled. Finally, the "$2M$-M" treatment considered the reverse order where the first part of the session involved the $2M$ environment and the second part involved the M environment, that is, the money supply was cut in half. In all four cases, subjects were not informed about the nature of the environment they would face in the second part of the experiment until the first part had been concluded. That is, the changes in the environment of the second part of the study can be regarded as being unknown to subjects in advance.

As noted, each part of a session consisted of several "supergames" which we referred to in the written instructions as "sequences." Each sequence consisted of an indefinite number of repetitions (periods) of a stage game. Each stage game involved two rounds, a DM round and a CM round. Every sequence began with the play of at least one, two-round stage game. At the end of each stage game, the sequence continued with another repetition (period) of the stage game with probability β and ended with probability $(1-\beta)$. If a sequence ended, subjects were told that "depending on the time available," a new indefinite sequence would begin. Specifically, our computer program drew a random number uniformly from the set $\{1,2,3,4,5,6\}$, and this was explained to subjects as simulating the roll of a six-sided die. If the number drawn was not a 6, then the sequence continued with another round; otherwise, if a 6 was drawn, the sequence ended. In this manner we induced a discount factor or continuation probability of $\beta = 5/6$.[9]

In practice, we let our computer program determine the indefinite sequence lengths using the random termination method in the very first experimental session reported on in this article in real-time, that is without any intervention on our part. We then hard-coded in these exact same sequence lengths for all remaining sessions, so as to minimize differences across our sessions due to varying sequence lengths.[10]

At the start of each and every new indefinite sequence of our money, M, or doubled money, $2M$, environments, prior to the first DM round, each subject in our Lagos-Wright economy was endowed with either $M/2N$ "tokens" or $2M/2N$ tokens, depending on the treatment.[11] In these sessions, subjects were also informed about the total number of tokens, $M = 112$ or $2M = 224$. They were also informed that the total token quantity was fixed and that they would not get any further endowment of tokens for the duration of that sequence. Subjects were further instructed that if a sequence ended, their token balances would be set to zero. However, if a sequence continued with a new period, their token balance, as of the end of the last period, would carry over to the new period of the sequence. In the NM environment, there was no money and thus no initial endowments of or instructions regarding tokens.

Within a period (stage game), the DM round began with a random pairwise matching of all $2N$ subjects to form N pairs. Within each pair, one player was chosen with probability 1/2 to be the producer and the other player was designated as the consumer for that round. We suggested that subjects think of this determination as the result of a coin flip and recognize that they would be a consumer (producer) in one half of all DM rounds, on an average. Subjects were instructed that all random pairings and assignments were equally likely. For the DM we induced the utility function $u(q) = A \log(1+q)$ over consumption and the cost function $c(q) = C\mathrm{q}$ over production of the decentralized good. These functions were presented to subjects in a payoff table showing how a certain quantity q of the decentralized good translated into a positive number, $A \log(1+q)$, of "points" in the case of consumption or a negative number, $-Cq$, of points in the case of production. Subjects were instructed in how to use that table to calculate their earnings in various scenarios. At the start of each session each subject was given an initial endowment of 20 points so as to minimize the possibility that any subject ended up with a negative point balance; indeed, we can report that no subject ended any of our experimental sessions with a negative point balance. Importantly, subjects were specifically instructed that "Tokens have no value in terms of points," that is, tokens had *no redemption value*. Like fiat money, tokens were intrinsically worthless with regard to the points that subjects accrued over the course of a session (from consumption and less production) and it was these point totals that were used to determine subjects' earnings from the experiment. Notice that the environment is potentially merciless in the sense that if no producer agrees to produce, there is no consumption and hence no points earned by any agent.[12]

Consumers moved first and were asked to form a "proposal" as to how much of the decentralized good they wanted their randomly matched producer to produce for them and in the money treatments, how many tokens, if any, the consumer was willing to offer the producer for the quantity requested. Consumers were informed of both their own and their matched producer's current token balances prior to formulating their proposal. Consumers were restricted to requesting quantities of the decentralized good, q, in the interval $[0, \overline{q}]$ though fractional units were allowed. In the money treatments they could also offer their matched producer d units of their current period token balance as part of their proposal. It was made clear that token (money) offerings were voluntary; subjects were instructed that the amount of tokens offered, d, could range between 0 and their currently available token balance, inclusive, and that fractional units were also allowed. Thus, each consumer formulated a proposal, (q,d) in treatments with money and a proposal, q, in the NM treatments, which was then anonymously transmitted to their matched producer.

Producers moved second and were first informed of their matched consumer's proposal. Producers were further informed about the consumer's benefit from receiving the proposed quantity q, $u(q)$, and of their own cost from producing quantity q, $u(q)$. In the money treatment, producers were also informed of both the consumer's and their own currently available token balances as well as the quantity of tokens, d, the consumer was offering them in exchange for producing q units. Producers then had to decide whether to accept or reject the consumer's proposal. If the producer accepted the proposal, then it was implemented: producers produced quantity q at a cost to themselves of $c(q)$ points. The consumer consumed quantity q yielding him or her a benefit of $u(q)$ points. In the money treatments the proposed quantity of tokens, d, if positive, was transferred from the consumer to the producer. If the producer rejected the proposal then no exchange took place; both members of the pair earned 0 points for the round and in the money treatments, their token balances remained unchanged. At the end of the decentralized round, subjects were informed of the outcome of that round: in particular, they were informed as to whether the proposal was accepted or not and were updated on any changes to their cumulative point totals. In the money treatments they also learned of any changes to their token balances. After this feedback was communicated, the decentralized round was over and the CM round began.

Within a period (stage game), the second, CM round brought together all $2N$ participants to participate in the meeting for the homogeneous and perishable "good X." Trade in the CM was organized via a trading post or "market game" as in Shapley and Shubik (1977). The specific trading post set up in our environment follows that of Green and Zhou (2005) and depends on whether subjects were in a M or NM environment. At the start of the centralized round, all subjects were asked whether they wanted to participate in the centralized trading post meeting. If they agreed to participate then they decided how much they wanted to produce of good X for the trading post, say $y \geq 0$. After that, subjects had to decide how much they wished to bid, b, for units of good X. In the NM environment, each subject was instructed that their individual bid, b_i, for units of good X could be any amount up to and including y_i, the number of units they had already committed to produce, that is, $0 \leqslant b_i \leqslant y_i$. In the money treatment, bids for good X had to be in money units and subjects were instructed that they could bid any amount of their currently available money holdings, m_i, but that their bid could not exceed their money holdings, that is, $0 \leqslant b_i \leqslant m_i$. After every subject had submitted their decisions, the market price of good X was determined by $P = \sum b_i / \sum y_i$. Subjects were further instructed that $P = 0$ if $\sum b_i = 0$ or if $\sum y_i = 0$ or both, in which case no trade took place. The realized payoff in the CM was known to be given by $U(b,y,P) = (b/P) - y$ since consumption is determined by b/P and preferences are linear in the CM. In the M environment, token holdings at the beginning of the next DM, m', were given by money holdings at the beginning of the previous CM, plus any proceeds from sales, minus any amount of tokens bid: $m' = m + Py - b$. As the population size, N, grows large, the theoretical predictions remain the same as for the Lagos and Wright (2005) model.

Points were subtracted or added to subjects' point totals from the DM round.

Following the completion of the CM round, subjects were updated on their new point totals or token holdings. Then a random number was drawn from the set $\{1,2,3,4,5,6\}$. If the random number drawn was not 6, the sequence continued on with another two-round period. In the money treatment, subjects' token balances as of the end of the CM were carried over to the decentralized round of the next period in the sequence. If the random number drawn was a 6, then the sequence ended. In the money treatment if a sequence ended, token balances were set to zero.

Subjects were instructed that once a sequence ended, depending on the time available a new indefinite sequence might begin. In each new sequence of a money treatment, all subjects would start the new sequence with $M/14 = 18$ tokens, or $2M/14 = 16$ tokens depending on whether it was the M or $2M$ treatment. Point totals, however, were not re-initialized between sequences and carried over from one sequence to the next. Approximately mid-way through each session, the experimenter announced the conclusion of the first part, which came only at the end of an indefinite sequence (when a 6 was rolled). Instructions for the second part were then handed out and read aloud. The second part also consisted of a number of indefinite sequences, and subjects earned points in both the decentralized and CMs of the second part of the session just as they had in first part; there was no change in the utility benefits from consumption or the costs of production in either the decentralized or CMs of each part of a session of this experiment. The only changes were with regard to the presence or absence of money or the total stock of money in circulation. Following the completion of the second and final part of the session, subjects answered a brief questionnaire and were then paid their accumulated point earnings from all sequences played in both parts of the session along with a \$5 show-up payment. Subjects' cumulative point totals from all periods of all sequences played were converted into cash at the end of the session at the fixed and known exchange rate of 1 token = \$0.20. Average total earnings were \$24.54 (standard deviation of \$6.06) for an approximately 2.5 hour session.

EXPERIMENTAL RESULTS

We report on data from 12 experimental sessions. As each session involved 14 subjects, we have data from a total of 168 subjects. Some characteristics of our 12 experimental sessions are given in Table 3. As the table reveals, we had three sessions of each of the four treatments. The first and second parts of each session are indicated in this table but are also reflected in the names given to each session, where NM = no money, M = money, and

Table 3. Characteristics of the 12 Experimental Sessions.

Treatment Name	Part 1 Treatment	Part 1 Seq Lengths; Periods	Part 2 Treatment	Part 2 Seq Lengths; Periods
NM-M-1	NM	6,2,7; 15 periods	M	4,12; 16 periods
NM-M-2	NM	6,2,7; 15 periods	M	4,12; 16 periods
NM-M-3	NM	6,2,7; 15 periods	M	4,12; 16 periods
M-NM-1	M	4,12; 16 periods	NM	6,2,7; 15 periods
M-NM-2	M	4,12; 16 periods	NM	6,2,7; 15 periods
M-NM-3	M	4,12; 16 periods	NM	6,2,7; 15 periods
M-2M-1	M	4,12; 16 periods	2M	6,2,7; 15 periods
M-2M-2	M	4,12; 16 periods	2M	6,2,7; 15 periods
M-2M-3	M	4,12; 16 periods	2M	6,2,7; 15 periods
2M-M-1	2M	6,2,7; 15 periods	M	4,12; 16 periods
2M-M-2	2M	6,2,7; 15 periods	M	4,12; 16 periods
2M-M-3	2M	6,2,7; 15 periods	M	4,12; 16 periods

2M = twice money. Hence, "NM-M-1" is the session number 1 of the treatment where the first part was the NM environment and the second part was the M environment. In addition, Table 3 reports the sequence lengths and total number of periods in each part of each session. Recall that after the first session, we hard-coded the sequence lengths and thus the total number of periods for each part and we kept these sequence lengths constant across sessions. For instance, in the NM-M treatment sessions, the first part always consisted of three sequences of lengths 6, 2, and 7 periods for a total of 15 periods. The second part always consisted of two sequences of lengths 4 and 12 periods for a total of 16 periods. Thus, combining the first and second parts, each session involved 31 periods, with each period involving both a DM round followed by a CM round.

Our experiment has yielded a number of interesting results which we summarize as several different findings.

NM-M and M-NM Treatments

We begin with an analysis of behavior in the NM-M and M-NM treatment sessions. Recall that in these sessions there was either no money (NM) or a constant total stock of 112 units of fiat money (M) or 8 units per capita. Our first finding concerns the acceptance of DM offers by producers in these sessions.

Finding 1. *The frequency with which DM offers are accepted in the NM-M and M-NM treatments is independent of whether or not there is a money object or of the treatment ordering.*

Support for Finding 1 comes from the second and fifth columns of Table 4 which reports the mean DM offer acceptance frequencies (DM Accept) in the No Money (NM) or Money (M) parts of the three NM-M and M-NM sessions.

Using the six pairs (NM, M) of mean acceptance frequencies for each of the six sessions, a Wilcoxon signed ranks test indicates that we cannot reject the null hypothesis of no difference in acceptance frequencies between the NM or M parts of each of these sessions ($p = .753$). This result is also confirmed by the Wilcoxon-Mann Whitney test on the acceptance frequencies of the first part of the NM-M or M-NM treatment sessions ($p = .5$).

Further support comes from the first column of Table 5 which reports the results of a GLS regression analysis of *individual* producers' acceptance decisions in all periods of all NM-M and M-NM sessions. The first column reports results of a regression of the producer's DM offer acceptance decision on a constant and two dummy variables: M, a dummy variable equal to 1 if the economy had money and OrderM-NM a second dummy variable

Table 4. Mean DM Offer Acceptance Frequencies, DM Traded Quantities, q, and Welfare as a Percentage of the First Best in the Two Parts of Each Session of the NM-M and M-NM Treatments.

NM-M	No Money			Money		
Session	DM Accept	DM q	Welfare	DM Accept	DM q	Welfare
NM-M-1	0.448	1.506	0.251	0.348	2.100	0.212
NM-M-2	0.343	1.291	0.173	0.295	1.559	0.167
NM-M-3	0.457	2.579	0.358	0.429	1.797	0.288
All 3	0.416	1.792	0.261	0.357	1.819	0.222
M-NM	Money			No Money		
Session	DM Accept	DM q	Welfare	DM Accept	DM q	Welfare
M-NM-1	0.429	6.656	0.363	0.419	1.117	0.191
M-NM-2	0.446	3.049	0.342	0.295	0.625	0.084
M-NM-3	0.545	4.050	0.444	0.438	1.412	0.242
All 3	0.473	4.585	0.382	0.384	1.051	0.172

Table 5. GLS Regression Analysis of Treatment Effects and Time on DM Behavior in the NM-M and M-NM Treatments.

Variable	DM Offer Accepted	DM Quantity Traded
Constant	0.378***	1.068**
	(0.037)	(0.519)
M	0.015	1.706*
	(0.039)	(0.938)
OrderM-NM	0.045	1.150**
	(0.045)	(0.458)
R^2	0.03	0.17
Nobs	1,302	524

*,**,*** Significance at the 10%, 5%, and 1% levels.

equal to 1 if the treatment order of the session was M in the first part and NM in the second part. Our random effects regression analysis on individual subject data involved robust clustering of standard errors on each of the six sessions. The results in the first column of Table 5 indicate that the mean DM acceptance frequency was 37.8 percent (the coefficient on the constant term), and that the presence or absence of money or the treatment ordering were not significant factors in producers' acceptance decisions as indicated by the insignificance of the coefficients on the M and OrderM-NM dummy variables.

We next consider whether the presence or absence of fiat money (tokens) has an effect on the DM quantities that producers agreed to produce for their matched consumers, that is, on *traded* DM quantities.

Finding 2. *In the NM-M and M-NM treatments, mean traded DM quantities are higher with money than without money. However, the impact of money on DM quantities is more pronounced in the M-NM treatment as compared with the NM-M treatment.*

Support for Finding 2 comes again from Tables 4–5. The third and sixth columns of Table 4 show the mean quantities traded in the DM market of the NM or M treatments. Notice that mean traded DM quantities in the M part of each session are, with a single exception (session NM-M-3), greater than mean traded DM quantities in the NM part of each session. While we do not have enough *session-level* observations to establish whether these differences are statistically different from one another at conventional significance levels, our random effects regression analysis of individual traded quantities from the six NM-M and M-NM sessions (with clustering of errors on session-level observations) suggests that the presence of money positively affects the DM quantity traded. In particular, the third column of Table 5 reports on a regression of DM quantity traded on the same two dummy variables used to understand exchange decisions. As the regression results indicate, the baseline NM mean traded quantity is 1.068 units (the coefficient on the intercept term in the regression) and this amount is substantially increased by an additional 1.706 units (for a total of 2.774 units) when money is present as indicated by the statistically significant coefficient on the M dummy term. Notice further that, in support of the second statement of Finding 2, the treatment order also matters for the DM traded quantity as indicated by the significantly positive coefficient of 1.15 on the OrderM-NM dummy variable. Specifically, the DM quantity is further increased from 2.774 units to 3.924 units if the treatment order was M-NM as opposed to the opposite NM-M treatment order. The amount 3.924 is close to the unique monetary equilibrium prediction that four units are traded in the DM.

Intuitively, in the NM-M treatment in the initial absence of money – the first NM part of this treatment – subjects coordinated on a low-level DM quantity to trade. The introduction of money in the second M part of the NM-M treatment sessions did not succeed in increasing the DM quantity by very much as is more clearly revealed in Table 4 where the overall average DM traded quantity was 1.792 units in the NM part and only slightly higher at 1.819 units in the M part. On the other hand, in the M-NM treatment sessions, the presence of a stock of money resulted in a much greater traded DM quantity in the M part; the average of the session observations was 4.585 units which again is close to the monetary equilibrium prediction of four units and much greater than the 1.7292 units traded on average in the first part of the NM-M treatment sessions. Furthermore, when money was removed from the economy in the second part of the M-NM treatment sessions, there was a precipitous drop-off in the mean DM quantity traded, from 4.585 units down to an average of 1.051 units again as revealed in Table 4. This lower level of traded DM quantity is more typical of the NM treatment sessions and also in line with the quantities reported of Duffy and Puzzello (2014).

As an alternative comparison, let us focus on just the first part of each of the six NM-M or M-NM treatment sessions. Fig. 1 provides a graphical illustration of the mean traded DM quantities in the first part of each of these six sessions using the relevant data reported in Table 4. This figure makes it clear that mean traded DM quantities are much larger in

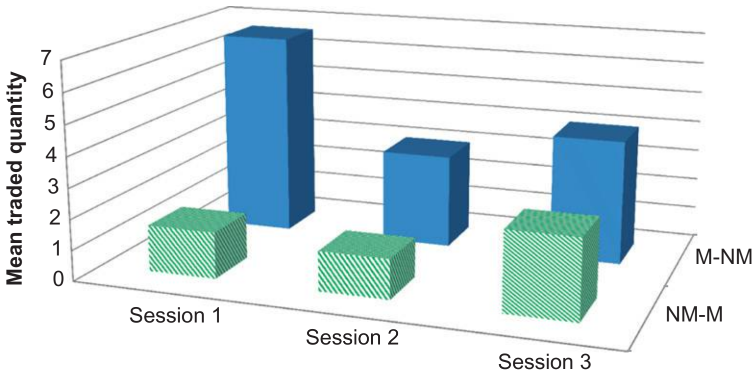

Fig. 1. Average DM Quantity Traded in the First Part of the Three NM-M and of the Three M-NM Sessions.

the first part of the M-NM treatment sessions where there was a constant stock of fiat money (M) as compared with the first part of the NM-M treatment sessions where there was no fiat money (NM). Indeed, a Wilcoxon-Mann Whitney test on the six session-level averages confirms this impression; we can reject the null of no difference in mean traded quantities in favor of the alternative that mean traded DM quantities are higher with money than without money in the first parts of these sessions ($p = .10$, two-sided test, smallest p-value with just three observations per treatment).

A consequence of Findings 1−2 is that welfare is higher in economies that start out with a supply of the token money object (as in our M-NM treatment) as compared with economies that do not start out with a supply of the token money object (as in our NM-M treatment), which is consistent with Duffy and Puzzello (2014). Furthermore, in economies that start out with a token object, welfare drops significantly when that token object is later taken away as in the M-NM treatment sessions. However, the same is not true in the reverse-order NM-M treatment sessions; in the latter, the low quantity exchanged in the first NM part of the session spills over to the second, M part of the session, where DM quantities are not much different and consequently there is not much improvement in welfare. We summarize this result as follows:

Finding 3. *Welfare is higher with money than without money in the M-NM treatment sessions where money is introduced in the first part. However, in the NM-M treatment sessions where money is only later introduced in the second part, welfare is not improved by the introduction of money.*

Support for Finding 3 comes from Table 4, specifically from the welfare measure reported under the heading "Welfare" which indicates the percentage of the first best level of welfare that subjects were able to achieve in the first and in the second parts of the NM-M and M-NM treatments.[13] We observe that welfare is higher in the first part of the M-NM treatments where there is a supply of money than in the second part where there is no money. On the other hand, if the economy starts without money, as in the first part of the NM-M treatment sessions, the introduction of money does not seem to be welfare-improving. Further confirmation of these impressions is provided in Table 6 where we use welfare ratios for every *period* of the NM-M and M-NM sessions as a dependent variable in a fixed effects regression that clusters errors at the session level.[14]

The regression in the first column (both NM-M, M-NM) uses period welfare ratios from all six NM-M and M-NM sessions combined. There we find that, over all sessions, the presence of money is welfare improving as indicated by the positive and significant coefficient on the M dummy variable (representing the treatment where money was present). We also find that, consistent with Table 4, the treatment order matters; welfare is higher in the M-NM treatment order as compared with the NM-M treatment order as indicated by the coefficient on the OrderM-NM dummy variable. In the second and third columns of Table 6, we focus on just the NM-M or M-NM treatment session data separately. There we see confirmation that in the NM-M treatment order, the introduction of money has no significant impact on the welfare ratio. However, in the M-NM treatment order, the introduction of money has a significant impact on the welfare ratio and

Table 6. Regression Analysis of Period-by-Period Welfare Ratios in the NM-M and M-NM Sessions.

Variable	Both NM-M, M-NM	NM-M Only	M-NM Only
Constant	0.197***	0.261***	0.172***
	(0.021)	(0.022)	(0.022)
M	0.086***	−0.038	0.211***
	(0.023)	(0.031)	(0.031)
OrderM-NM	0.040*		
	(0.023)		
Nobs	186	93	93
R^2	0.07	0.01	0.34

*,**,*** Significance at the 10%, 5%, and 1% levels.

this effect is so large that it also obtains in the combined data sample in the first column. The finding that welfare is not increasing with the introduction of money in the NM-M treatment order appears attributable to the negligible increase in DM traded quantities in the second part of the NM-M treatment sessions in combination with a slight decrease in DM offer acceptances from the first NM part to the second M part – see Table 4. It appears that, once established, social norms of low-level gift exchange are very difficult to abandon and may persist despite the introduction of money (and therefore prices).

Regarding prices in the NM-M and M-NM treatments, Table 7 reports mean DM trade prices (for the M part of each session only) along with CM market prices for both the NM and M parts. Recall from Table 2 that for our parameterization of the model, the monetary equilibrium prediction when $M/2N = 8$ (as in the M parts of these sessions) is for both the DM price, p and CM price, P, to equal 2.

We observe that for the M part of the M-NM treatment sessions, the mean DM price is 1.484, which is close to, but lower than the monetary equilibrium prediction of 2. The CM price in the M part of these sessions is however very close to 2, averaging 2.067 across the three M-NM treatment sessions (the median is 2.053. This evidence not only confirms that money is being used (otherwise there would be no DM prices), but suggests that

Table 7. Mean or Median Prices in the DM or CM of the Two Parts of Each Session of the NM-M and M-NM Treatments.

	No Money			Money		
NM-M Session	Mean DM price	Mean CM price	Median CM price	Mean DM price	Mean CM price	Median CM price
NM-M-1	N/A	0.982	0.988	2.403	5.258	4.093
NM-M-2	N/A	0.981	0.994	2.659	13.750	4.483
NM-M-3	N/A	0.977	0.981	3.534	4.576	4.538
All 3	N/A	0.980	0.987	2.865	7.861	4.371
	Money			No Money		
M-NM Session	Mean DM price	Mean CM price	Median CM price	Mean DM price	Mean CM price	Median CM price
M-NM-1	1.124	1.452	1.259	N/A	0.949	0.967
M-NM-2	2.017	3.028	3.332	N/A	0.966	1.000
M-NM-3	1.310	1.725	1.566	N/A	0.971	0.999
All 3	1.484	2.068	2.053	N/A	0.962	0.988

subjects were close to coordinating on the unique monetary equilibrium in the M part of the M-NM treatment sessions.

By contrast, prices in the M part of the NM-M treatment sessions are at odds with the monetary equilibrium predictions; as Table 7 reveals, DM trade prices are greater than 2, averaging 2.865 and CM prices are considerably higher, averaging 7.861, though the median CM price is lower, at 4.371. These greater-than-predicted prices in the M part of the NM-M treatment are really just a reflection of the fact that DM traded quantities are too low in the M part of the NM-M treatment sessions relative to the monetary equilibrium prediction of four units traded per period; with lower-than-equilibrium DM traded quantities and a constant money supply, both DM and CM prices will necessarily be higher than equilibrium predictions.

In the NM part of both the M-NM and NM-M treatment sessions, CM prices are very close to 1, reflecting a common strategy that subjects offer to bid for as many units of the centralized good X as they offered to produce; in the NM part of these sessions, there is no need to rebalance monetary holdings and so the price is valuable only as a signal of the coordinated behavior of market participants in the CM.

As suggested in the Introduction, the natural order of events in human history was that nonmonetary gift-exchange regimes preceded the current, modern fiat money regime of impersonal exchange. However, when we implement such a regime change in the laboratory (from NM to M) we find that while money is used and there is (in two of three sessions) a slight increase in the amount of DM exchange, the behavior of subjects departs considerably from the new and unique monetary equilibrium prediction and there is no welfare improvement. On the other hand, if, counter to history, we start with a supply of money, then behavior conforms more closely to the monetary equilibrium predictions for the M part of that treatment and taking away money in the second part leads to a significant drop-off in exchange and welfare. We speculate that the adjustment from the NM to the M regime may take longer than is allowed for in the compressed time frame of our experimental study. We further note that monetary exchange systems often involve an intermediate transition phase from a regime of pure gift exchange to one of commodity money and then on to fiat money as opposed to the more stark transition that we attempt to engineer from a pure gift-exchange economy to one involving only fiat money. We would add that monetary regimes are often accompanied by legal restrictions requiring the use of money (e.g., to pay taxes) and that such restrictions are completely absent in the framework that we study here. These omissions are potentially important factors in understanding our finding of treatment order effects.

M-2M and 2M-M Treatments

We now turn to our second main treatment exploring the neutrality-of-money proposition as first set forth by Hume and which plays a fundamental role in the quantity theory of money. Recall that in these treatments, the total money stock was either 112 total units, or 8 units per capita as in the M treatment, or twice this amount, 224 total units, or 16 units per capita as in the 2M treatment. Our first finding concerns the acceptance of DM offers in these treatments.

Finding 4. *There is no difference in DM offer acceptance rates between the first and second parts of either the M-2M or the 2M-M treatments.*

Support for Finding 4 comes from Tables 8 and 9. The second and fifth columns of Table 8 report mean DM offer acceptance frequencies by producers in the M-2M and 2M-M treatments; these acceptance frequencies are all quite similar, lying between .425 and .473 on average. Indeed, a Wilcoxon signed ranks test on matched pairs of acceptance frequencies yields no significant difference ($p=0.75$ for both M-2M and 2M-M). Further support comes from the first column of Table 9 which reports the results of a random effects regression of producer's DM offer acceptance decisions on a constant and two dummy variables: $2M$, a dummy variable

Table 8. Mean DM Offer Acceptance Frequencies, DM Traded Quantities, q, and Welfare as a Percentage of the First Best in the Two Parts of Each Session of the M-2M and 2M-M Treatments.

M-2M	Money			2×Money		
Session	DM Accept	DM q	Welfare	DM Accept	DM q	Welfare
M-2M-1	0.464	3.447	0.383	0.448	2.865	0.355
M-2M-2	0.420	4.021	0.330	0.476	3.380	0.381
M-2M-3	0.536	4.690	0.457	0.390	5.195	0.351
All 3	0.473	4.053	0.390	0.438	3.813	0.363
2M-M	**2×Money**			**Money**		
Session	DM Accept	DM q	Welfare	DM Accept	DM q	Welfare
2M-M-1	0.505	3.627	0.444	0.536	2.076	0.373
2M-M-2	0.362	2.372	0.302	0.330	2.298	0.227
2M-M-3	0.410	3.884	0.347	0.446	1.850	0.296
All 3	0.425	3.294	0.365	0.438	2.075	0.298

Table 9. GLS Regression Analysis of Treatment Effects and Time on DM Behavior in the M-2M and 2M-M Treatments.

Variable	DM Offer Accepted	DM Quantity Traded
Constant	0.467***	3.631***
	(0.019)	(0.472)
2M	−0.025	0.820
	(0.031)	(0.506)
Order2M-M	−0.024	−0.972*
	(0.045)	(0.527)
R^2	0.01	0.05
Nobs	1,302	571

*,**,*** Significance at the 10%, 5%, and 1% levels.

equal to 1 if the money supply was 2M, and Order2M-M a second dummy variable equal to 1 if the treatment order of the session was 2M in the first part and M in the second part.

The regression results in the first column of Table 9 suggest that the mean DM offer acceptance frequency is 46.7 percent and that neither the doubling of the money supply nor the treatment order has any effect on DM offer acceptance frequencies as indicated by the insignificance of the coefficients on the 2M and Order2M-M dummy variables.

We next consider whether the change in the money supply has any real effects on DM traded quantities.

Finding 5. *Consistent with the neutrality of money proposition, there are no real effects on DM traded quantities if the money supply is M or 2M. However, this neutrality result is more pronounced in the M-2M treatment as compared with the 2M-M treatment.*

Support for Finding 5 comes from Tables 8 and 9. Table 8 suggests that mean DM traded quantities (DM q) in the first part of the M-2M and 2M-M treatment sessions are very similar to one another and are close to the monetary equilibrium prediction of four DM units exchanged; these mean quantities from the first parts of all M-2M and 2M-M sessions are also illustrated in Fig. 2. Indeed, a Wilcoxon-Mann Whitney test using the six session-level observations illustrated in Fig. 2 indicates that we cannot reject the null of no difference in DM traded quantities between the first (M) part of the M-2M treatment sessions and the first (2M) part of the 2M-M treatment sessions ($p = .275$) suggesting that a doubling of the

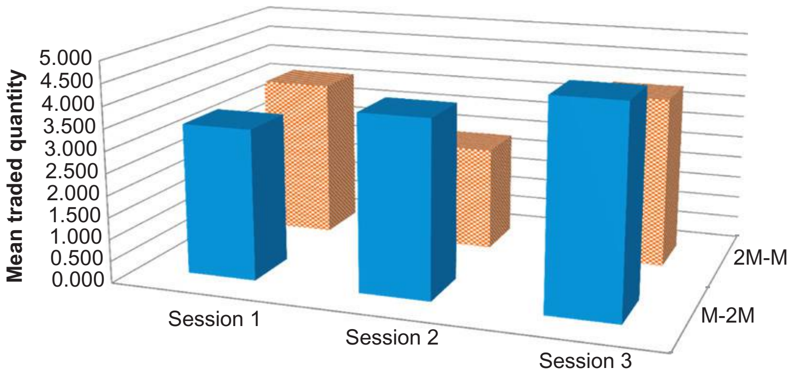

Fig. 2. Average DM Quantity Traded in the First Part of the Three M-2M and of the Three 2M-M Sessions.

money supply has no real effects on DM traded quantities, at least in the first part of these sessions.

On the other hand, we observe in Table 8 that there is some drop-off in the mean DM traded quantities in the second parts of both the M-2M and the 2M-M treatment sessions and that in support of the second statement of Finding 5 this decline appears to be much larger in the second part of the 2M-M treatment sessions as compared with the second part of the M-2M treatment sessions.

Further evidence in support of Finding 5 comes from the third column of Table 9 which reports on a regression of DM traded quantities on the same two dummy variables used to understand exchange decisions. The regression results indicate that the baseline quantity of DM exchange in the M treatment is 3.631 units, which is again close to the monetary equilibrium prediction of four units. A doubling of the money supply does not have a significant effect on this quantity as indicated by the statistical insignificance of the coefficient on the 2M dummy variable. However, in support of the last statement of Finding 5, we also observe that the coefficient estimate on the treatment order dummy, Order2M-M, is significantly negative; the latter finding means that mean traded quantities in the DM market are 0.972 of a unit lower if the treatment order was 2M-M as opposed to the baseline M-2M order. This same finding is also found in Table 8 where DM q is lower in both the 2M and M parts of the 2M-M treatment sessions as compared with the M and 2M parts of the M-2M treatment sessions.

An implication of Findings 4 and 5 is the following:

Finding 6. *Welfare is unaffected by the doubling of the money supply in the M-2M treatments but is reduced by the reduction of the money supply in the 2M-M treatments.*

Support for Finding 6 comes from the welfare session averages reported in Table 8. There we see that for the M-2M treatment sessions, there is not much change in our welfare measure (percentage of the first best welfare achieved) as the money supply was doubled from M to 2M. Indeed, using the three pairs of welfare measures for the three M-2M treatment sessions, a two-sided Wilcoxon signed ranks test indicates that we cannot reject the null of no difference in welfare between the M and 2M parts of these treatments ($p = .75$). However, applying the same test to the three pairs of welfare measures for the 2M-M treatment sessions, we find that welfare is lower in the M part as compared with the 2M part ($p = .25$, which is the lowest p-value possible with just three observations). The latter finding is mainly attributable to the large fall-off in the DM quantity traded in the M part of two of the three 2M-M sessions, since acceptance rates do not vary too much across the M and 2M treatments.

Disaggregating further, Table 10 reports fixed effects regressions with clustering of standard errors on individual sessions where the dependent variable is the period-by-period welfare ratios relative to the first best welfare in the M-2M and 2M-M sessions regressed on treatment dummy variables (as was done earlier in Table 6 for the NM-M and M-NM treatment sessions).

Table 10. Regression Analysis of Period-by-Period Welfare Ratios in the M-2M and 2M-M Sessions.

Variable	Both M-2M, 2M-M	M-2M Only	2M-M Only
Constant	0.367***	0.390***	0.298***
	(0.022)	(0.025)	(0.025)
2M	0.019	–0.027	0.066*
	(0.025)	(0.036)	(0.036)
Order2M-M	–0.047*		
	(0.025)		
Nobs	186	93	93
R^2	0.02	0.01	0.04

*,**,*** Significance at the 10%, 5%, and 1% levels.

Combining all data from the M-2M and 2M-M sessions (first column) we see that the impact of the treatment change from M to 2M has no effect on period welfare ratios as indicated by the insignificance of the 2M dummy (equal to 1 in the 2M treatment). On the other hand, we note that the coefficient on the order dummy variable, Order2M-M, is negative and significant, indicating a treatment order effect wherein welfare is lower if the order is 2M-M as opposed to the baseline M-2M treatment ordering. Indeed, decomposing the data further by the treatment order, we see in the second and third columns that period welfare measures are unaffected by the doubling of the money supply in the M-2M treatment sessions, but that welfare is higher in the 2M part of the 2M-M treatment sessions than in the M part of those same sessions. The latter finding is mainly attributable to the large fall-off in the DM quantity traded in the M part of two of the three 2M-M sessions, since acceptance rates do not vary too much across the M and 2M treatments.

A further implication of the neutrality-of-money-proposition is that prices should double in the 2M treatment relative to the M treatment. This prediction should hold for both the DM and CM prices. We again find some mixed support for this prediction:

Finding 7. *In the M-2M treatment, decentralized and centralized market prices approximately double with the doubling of the total money stock from M to 2M and these prices are in line with monetary equilibrium predictions. By contrast, prices in the 2M-M treatment do not change or change in the wrong direction in response to a decrease in the money supply from 2M to M.*

Support for Finding 7 comes from Tables 11 and 12. Table 11 reports mean traded prices in both the DM and CM markets of each M-2M and 2M-M treatment session. In the M-2M treatment sessions we observe that mean DM and CM prices are in a neighborhood of the equilibrium prediction of 2 in the M part and increase to a neighborhood of the equilibrium prediction of 4 in the 2M part (we will be more precise about this below). By contrast in the 2M-M treatment sessions, contrary to equilibrium predictions, DM prices increase from the 2M part to the M part and CM prices are essentially unchanged.

To quantify these effects more precisely, Table 12 reports a simple regression analysis where the DM traded quantity, q, DM traded prices, p and CM market prices P are regressed on a constant and a dummy variable, 2M which was equal to 1 if the money stock was doubled to 2M and was 0 otherwise (if the money stock was M). Note that by contrast with the

Table 11. Mean or Median Prices in the DM or CM of the Two Parts of Each Session of the M-2M and 2M-M Treatments.

	Money			2×Money		
M-2M Session	Mean DM price	Mean CM price	Median CM price	Mean DM price	Mean CM price	Median CM price
M-2M-1	1.784	3.043	2.859	6.253	7.161	2.859
M-2M-2	1.410	2.925	1.551	3.266	6.227	4.808
M-2M-3	0.964	1.825	1.512	2.569	3.489	3.285
All 3	1.386	2.598	1.974	4.030	5.626	3.651
	2×Money			Money		
2M-M Session	Mean DM price	Mean CM price	Median CM price	Mean DM price	Mean CM price	Median CM rice
2M-M-1	3.100	4.954	4.689	4.429	4.003	3.796
2M-M-2	2.289	4.275	3.337	3.822	5.781	3.784
2M-M-3	2.889	4.916	4.591	3.142	3.006	2.831
All 3	2.759	4.715	4.206	3.797	4.263	3.470

Table 12. Regression Analysis of Quantity and Price Behavior in Response to Changes in the Money Supply.

Variable	M-2M			2M-M		
	DM q	DM p	CM P	DM q	DM p	CM P
Const.	4.12***	1.46***	2.597***	2.136***	3.955***	4.263***
	(0.350)	(0.254)	(0.390)	(0.093)	(0.532)	(0.816)
2M	−0.238	2.67***	3.028***	1.895***	−1.113**	0.126
	(0.373)	(0.947)	(0.725)	(0.182)	(0.508)	(0.821)
Nobs	293	290	93	278	276	93
R^2	0.01	0.05	0.17	0.01	0.04	0.01

*,**,*** Significance at the 10%, 5%, and 1% levels.

prior regression analyses of Tables 5 and 9 we have here *disaggregated* the data according to the treatment order, that is, either, M-2M or 2M-M, as we are interested in effects of changes in M on prices and so we do not include a treatment order dummy in this regression analysis. The regression results confirm Finding 5 that in the M-2M treatment, the change from M to 2M results in no significant change in quantities exchanged in the DM trading round; the coefficient on the constant term is 4.12 which is significantly different from zero and close to the monetary equilibrium prediction of $q=4$, but the coefficient on 2M is not significantly different from zero indicating no real effect from the change in the money supply on the quantity exchanged. Also consistent with the neutrality-of-money proposition, the change from M to 2M results in a significant increase in DM prices from 1.46 to 4.13, which approximates the unique monetary equilibrium prediction of a rise from DM $p=2$ to DM $p=4$. In the M-2M treatment, the CM price P also increases significantly from 2.597 to 5.628, which is somewhat higher, but in the right direction of the predicted rise from CM $P=2$ to CM $P=4$ for this treatment. Thus for the M-2M treatment, consistent with the neutrality-of-money proposition, the doubling of the money supply has no real effects but does result in an approximate doubling of both the DM and CM prices.

By contrast, in the 2M-M treatment, Table 12 reveals that the change from 2M to M has some real effects on DM traded quantities. In particular, real DM traded quantities are significantly higher – by 1.895 units on average – in the first 2M part as compared with the second M part of the 2M-M treatment sessions. Also inconsistent with the neutrality-of-money proposition, DM traded prices are significantly *lower* in the 2M part of the 2M-M treatment as indicated by the negative and significant coefficient on the 2M dummy variable and CM prices are unaffected by the change in the money supply from 2M to M as indicated by the insignificance of the coefficient on the 2M dummy variable. The latter findings, which stand in contrast to those found for the M-2M treatment, may reflect the fact that subjects in our experiment have limited life experience with *decreases* in the money supply and an associated deflation of the price level and may not have immediately known how to adjust to this new setting in the limited time frame of our experimental sessions. Alternatively, these findings may reflect some kind of behaviorally-based aversion to price reductions as has been documented using field data, for example, by Bewley (1999). Such findings are also broadly consistent with other experimental studies (reviewed in Section "Related Literature") that exhibited an asymmetric response in nominal prices to positive and negative shocks (e.g., Fehr & Tyran, 2001 and Noussair et al., 2012).

CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

This article provides further evidence on the coordination role played by monetary exchange in random search environments following up on experiments by Camera and Casari (2014) and Duffy and Puzzello (2014) by using a within-subject experimental design so as to more carefully explore the impact of monetary regimes relative to nonmonetary regimes and the impact of changes in the money supply on real activity and prices. The control of the laboratory, and especially the within-subject experimental design that we employ in this article enables us to be clearer about the causal mechanisms underlying real economic activity and price determination. Furthermore, monetary policy experiments of the type we investigate here, namely a doubling of halving of the money supply, are not readily implementable in the field, and this fact provides another motivation for our laboratory investigation.

We have found that the presence of money increases real exchange activity relative to the absence of money but that the overall welfare benefit of introducing money may depend on the order in which money is introduced. Our experimental findings also suggest that, consistent with the neutrality-of-money proposition, a doubling of the money supply has no real effects, and is associated with a doubling of prices. However, inconsistent with that neutrality proposition, we also find that a reduction in the money supply by half can have real effects and does not lead to a fall in prices by the same proportion.

As we noted in the Introduction, the order of events in the history of human exchange is that gift-exchange regimes preceded monetary exchange regimes. In our experiment, the transition from a nonmonetary gift-exchange regime to a monetary exchange regime is not found to be welfare improving and so an important topic for future research is to understand why this may be the case. One obvious omission that we have already alluded to is that our monetary regime does not involve any legal restriction to use money in exchange (e.g., to pay taxes) and such legal restrictions might have played an important role historically in the transition from gift exchange to monetary exchange systems. A second omission from the gift-exchange regime we consider is the use of any kind of accounting or record-keeping credit/debit ledgers that may have obviated the need for a money object, and which were also importantly historically (see Graeber, 2011). A third omission is that we have bypassed a potentially important intermediate step, namely, that of a *commodity-money* exchange regime where the good used as money has some value in use (utility value) apart from its value in exchange.[15] It may be that the transition from a pure gift-exchange regime involving only real costs and benefits to a monetary exchange regime involving the further use of fiat objects having no real intrinsic value requires an intermediate phase involving commodity-money issuance (e.g., gold or silver coins) such as was also observed in the history of monetary exchange. We leave the study of these topics to future research.

NOTES

1. Eagleton and Williams (2007).

2. As Graeber (2011) emphasizes, there is no evidence for quid-pro-quo barter exchange systems as a predecessor to monetary exchange systems in the anthropological record. In fact the evidence points to the exact opposite order of events: historically, barter exchange "has mainly been what people who are used to cash transactions do when for one reason or another they have no access to currency" Graeber (2011, p. 40).

3. See Duffy (2014) for a more detailed literature review of experimental studies on money.

4. That is, the token (or fiat money) objects we consider have value only if agents believe those objects to have value and not because of any legal restrictions or cash-in-advance constraints requiring the use of token objects in exchange; these token objects are "intrinsically worthless" in the sense that they do not yield agents any utility.

5. The original Lagos and Wright model has a positive probability, $(1-\alpha)$, that agents remain unmatched, a positive probability δ of double coincidence meetings, and a probability σ of being a consumer or a producer. We simplify the model as we set α=1, δ=0, and σ=1/2. This does not affect the qualitative results.

6. If the money supply is instead equal to $2M$, then the action set is given by $[0,\overline{q}]\times[0,2M]$.

7. Note that the quantity q satisfying $u(\overline{q})=c(\overline{q})$ is such that $\overline{q}\in[21,22]$. For simplicity, we just chose $\overline{q}=22$.

8. Example instructions used in the NM-M treatment sessions are provided in the Appendix.

9. This random termination method for implementing infinitely repeated games in the laboratory is due to Roth and Murnighan (1978). See Fréchette and Yuksel (2013) for a comparison of random termination (RT) with other, theoretically equivalent methods; RT is found to generate the highest levels of cooperation in repeated Prisoner's Dilemma games.

10. Variations in sequence (supergame) lengths can have an effect on the extent of cooperative behavior as documented by Dal Bo and Fréchette (2011) in repeated Prisoner's Dilemma game experiments and by Engle-Warnick and Slonim (2006) in repeated trust game experiments. Holding the sequence lengths constant across treatments as is also done by Fréchette and Yuksel (2013), helps to minimize such variations, so that any observed differences in within-subject behavior can be attributed to treatment changes alone. This design choice was also necessitated by our use of a *within-subjects* design, as we had to ensure that we would be able to read instructions for and implement two different indefinitely repeated game environments within the period of time that we had recruited subjects for each experimental session.

11. While we will refer to experimental sessions involving tokens as the "money" treatment sessions, we were careful to avoid all use of the term "money" in the experimental instructions or on computer screens.

12. Recall however, that subjects were given an initial endowment of 20 points and also promised a show-up payment.

13. The welfare measure is calculated using utility benefits and costs in points accrued by all subjects over all supergames and periods of each of the six sessions. That amount is then divided by the number of points that could have been earned had subjects played according to the first best equilibrium where a quantity of $q = 6$ is exchanged in every decentralized meeting.

14. We use period-level data rather than individual-level data in these regressions since at the individual-level, there will be those who benefit, that is, consumers in the DM and those who incur losses, that is, producers in the DM. The period level welfare ratio aggregates these individual benefits and losses and thus provides a better measure of welfare per period.

15. In the language of experimental economics, such commodity monies have a fixed and known "redemption value" to subjects (as in Lian & Plott, 1998) whereas the token fiat money object that we use is known to subjects to have *no* redemption value; it serves only as a possible means to the end goal of acquiring consumption, as is also the case in fiat money regimes.

16. If $-q + b/P < 0$, then $b/P <$ q or $b < P$q, so $Pq - b > 0$.

17. If $-q + b/P < 0$, then $b/P <$ q or $b < P$q, so $Pq - b > 0$.

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APPENDIX

Instructions used in the NM-M treatment sessions. Other instructions are similar and available upon request from the authors.

Welcome to this experiment in the economics of decision making. Funding for this experiment has been provided by the University of Pittsburgh. If you follow these instructions carefully and make good decisions, you can earn a considerable amount of money that will be paid to you in cash at the end of the experiment. *Please, no talking for the duration of today's session.*

There are two parts to today's experimental session We will first go over the instructions for the first part. When we are done, each of you will have to answer a few brief questions to ensure that everyone understands these instructions. You will also have time to ask clarifying questions. Then, you will begin making your decisions using the computer workstations. After the first part is over you will receive instructions for the second part. You can earn money from both parts of today's session as will be made clear in the instructions for each part.

Overview – Part 1

There are 14 people participating in today's session. Each participant will make consuming, producing, buying, or selling decisions in a number of *sequences*. Each sequence consists of an unknown number of *periods*. Each period consists of two *rounds*. At the end of each two-round period, the computer program will draw a random number, specifically, an integer in the set {1,2,3,4,5,6}. Each of these six numbers has an equal chance of being chosen; it is like rolling a six-sided die. The program will display the random number chosen on all participants' screens. If the random number drawn is 1,2,3,4, or 5, the sequence will continue with another two-round period. If the random number drawn is 6, the sequence will end. Thus the probability a sequence continues from one period to the next is 5/6 and the probability it ends after each period is 1/6. If a sequence ends, then depending on the time available, a new sequence will begin.

You will start today's experiment with an endowment of 20 points. Over the course of a sequence you may gain or lose points based on the decisions you make as will be explained in detail below. Your point total will carry over from one sequence to the next. Your final point total from all sequences played will determine your earnings for this first part of the experiment. Each point you earn is worth $0.30.

Timing and Pairing

Recall that each period consists of two rounds. In the first round of each new period, the 14 participants will be randomly matched in seven pairs and make decisions with one another in a *Decentralized Meeting*. In the second and final round of each period, all 14 participants will interact together in a *Centralized Meeting*. We will now describe what happens in each of the two rounds of a period.

Round 1: Decentralized Meeting
At the beginning of each Decentralized Meeting – the first round of each period – each participant is randomly paired with one other participant. All pairings are equally likely. In each pair, one participant is randomly chosen to be the *Consumer* and the other is the *Producer*. At the start of each Decentralized Meeting round, you are equally likely to be assigned either role; it is as though a coin flip determines whether you are a Producer or Consumer in each round. In the Decentralized Meeting, a perishable good is produced and can be traded. This good is "perishable" because it cannot be carried over into any other round or period. Producers incur a cost in points for producing some quantity of this perishable good which is subtracted from their point total and Consumers receive a benefit in points from consuming some quantity of the perishable good which is added to their point total. Table A1 summarizes how costs and benefits are related to your point earnings. For example, if you are a Producer and agree to produce two units of the good, you incur a production cost of two points. If you are a Consumer and you succeed in consuming seven units of the good, you get a benefit of 14.56 points.

Consumers move first and must decide on how many units of the perishable good they want their matched Producer to produce for them – see Fig. A1. Consumers can request any amount of the good between 0 and 22 units inclusive (fractions allowed). After all Consumers have made their decisions, Producers are then presented with their matched Consumer's proposal (amount of good requested). Producers must decide whether to "Accept" or "Reject" the Consumer's proposal – see Fig. A2. If a Producer clicks the Accept button, the proposed exchange takes place: the Producer produces the requested amount of the good and incurs a cost in

Table A1. Cost and Benefit (in Points) for Producers and Consumers, Decentralized Meeting.

Quantity	Producer's Cost in Points	Consumer's Benefit in Points
0	0	0.00
1	−1	4.85
2	−2	7.69
3	−3	9.70
4	−4	11.27
5	−5	12.54
6	−6	13.62
7	−7	14.56
8	−8	15.38
9	−9	16.12
10	−10	16.78
11	−11	17.39
12	−12	17.95
13	−13	18.47
14	−14	18.96
15	−15	19.40
16	−16	19.83
17	−17	20.23
18	−18	20.61
19	−19	20.97
20	−20	21.31
21	−21	21.64
22	−22	21.95

points from doing so. The Consumer receives a benefit in points from consumption of the amount of the good produced by the Producer as part of the exchange. If the Producer clicks the Reject button, then no trade takes place: the point balances of both participants will remain unchanged.

After all decisions have been made the results of the Decentralized Meeting (round 1) are revealed. Any exchanges are implemented and we next move on to the Centralized Meeting – round 2.

Round 2: Centralized Meeting

In the second round of a period, all 14 participants have the opportunity to interact in a single Centralized Meeting (there is no pairwise matching in the Centralized Meeting). In the Centralized Meeting, each participant can decide whether to produce-and-sell units of a perishable good called "good *X*." Participants who choose to produce-and-sell units of good *X* can

Fig. A1. Consumer Decision Screen, Decentralized Meeting.

Fig. A2. Producer Decision Screen, Decentralized Meeting.

further choose to buy-and-consume units of good X. Participants can also choose not to produce or buy any units of good X.

The first decision screen you face in the Centralized Meeting is shown in Fig. A3. There you are asked how many units of good X you would like to offer to *produce-and-sell*. You can enter any number between 0 and 22 units

Fig. A3. Production of Good *X* Decision Screen, Centralized Meeting.

inclusive (fractions allowed). Call this quantity "q." If you do not want to produce and sell any units of good X then enter 0 in the first input box. After you have entered your choice for q click the red submit button.

If you offer to produce $q > 0$ units of good X, you may be able to sell those units of good X at the market price, P, to buyers of good X if there is some demand for good X (as explained below). After all participants have chosen how many units of good X to offer to produce, those participants who entered $q > 0$ units of good X are asked on a second, Centralized Meeting decision screen whether they would like to bid to *buy-and-consume* any units of good X – see Fig. A4. Each participant can bid to buy-and-consume any number of units of good X between 0 and q inclusive (fractions allowed), where q is again the quantity of good X they chose to produce-and-sell. Call the amount you offer to bid to buy-and-consume units of good X, "b," so that $0 \leq b \leq q$. If you do not want to bid to buy and consume any units of good X then enter 0 in the input box of the second Centralized Meeting screen. When you are done making this choice, click the red submit button.

Table A2 shows the points that you can earn from producing-and-selling or from buying-and-consuming units of good X. For instance, if you choose to produce and sell two units of good X and you are able to sell those units (more on this below), then producing those two units will cost you two points. If you are able to buy and consume seven units of good X (again, see below), this will give you a benefit of seven points.

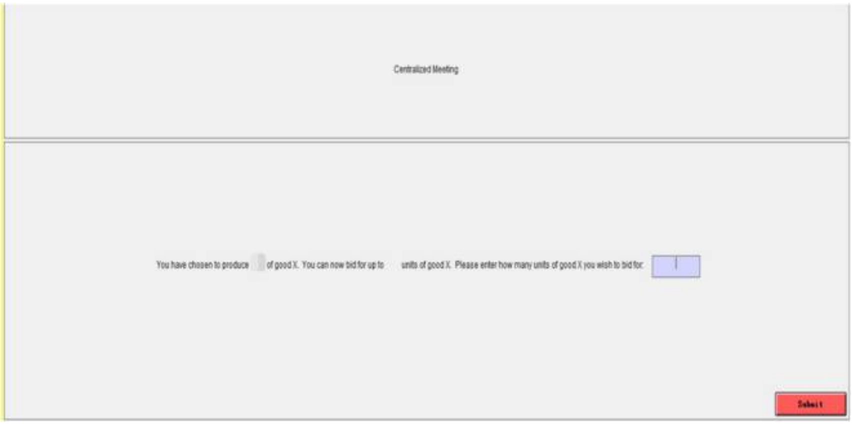

Fig. A4. Bid for Good X Decision Screen, Centralized Meeting.

After all participants have clicked the red submit button, the computer program calculates the total amount of good X that all participants have offered to produce and sell; call this: "Total Amount of Good X Produced." The program also calculates the total number of units of good X that all participants have bid to buy and consume; call this: "Total Amount Bid for Good X." Then the program calculates the *market price* of good X as follows:

If Total Amount of Good X Produced > 0 *and* Total Amount Bid for Good $X > 0$, then the market price of good X, P, is determined by:

$$P = \frac{\text{Total Amount Bid for Good } X}{\text{Total Amount of Good } X \text{ Produced}}$$

If Total Amount of Good X Produced = 0 *or* Total Amount Bid for Good $X = 0$ (*or both* are equal to 0), then $P = 0$.

Notice that you do not know the value of P when you are deciding whether to produce or bid for units of good X; P is determined only *after* all participants have made their Centralized Meeting decisions. Once the market price, P, is determined, if $P > 0$ then individuals who participated in the Centralized Meeting earn points according to the formula:

$$\text{Centralized Meeting payoff in points} = -q + \frac{b}{P} \tag{A.1}$$

The first term, $-q$, represents the cost to you of the q units of good X that you offered to *produce and sell*. The second term, b/P, represents the number of units of good X that you were able to *buy and consume* given your bid, b, and the market-determined price, P.

Notice several things. First, if $-q+b/P$ is negative (equivalently, if $Pq-b$ is positive[16]), so that you are a *net seller* of good X, then you lose points from the Centralized Meeting according to formula (A.1). Second, if $-q+b/P$ is positive (equivalently, if $Pq-b$ is negative) so that you are a *net buyer* of good X, then you earn additional points from the Centralized Meeting according to formula (A.1). Thus, if $P>0$, those who are net *seller-producers* of good X will leave the Centralized Meeting with *lower* point totals, while those who are net *buyer-consumers* of good X will leave the Centralized Meeting with *higher* point totals. Finally, note that if $P=0$,

Table A2. Cost and Benefit (in Points) for Producers and Consumers, Centralized Meeting.

Quantity Produced, q, *or* Quantity Bought, b/P	Produce-and-Sell Cost in Points	Buy-and-Consume Benefit in Points
0	0	0
1	−1	1
2	−2	2
3	−3	3
4	−4	4
5	−5	5
6	−6	6
7	−7	7
8	−8	8
9	−9	9
10	−10	10
11	−11	11
12	−12	12
13	−13	13
14	−14	14
15	−15	15
16	−16	16
17	−17	17
18	−18	18
19	−19	19
20	−20	20
21	−21	21
22	−22	22

or if you do not produce or bid for good X in the Centralized Meeting, then your point balance remains unchanged.

Players' new (or unchanged) point totals carry over to the Decentralized Meeting of the next period of the sequence, if there is a next period, which depends on the random number drawn. If the sequence does not continue with a new period, then all participants' point totals for the sequence are final. Depending on the time available, a new sequence may begin.

Information

After each Decentralized Meeting round, all participants will be informed about their point earnings and those of the participant with whom they were paired. Nobody will ever be informed about the identity of the participant with whom they were paired in any round of this experiment. Following round 2 (Centralized Meeting) you will see your point totals both for the Decentralized Meeting round 1, the Centralized Meeting round 2, the period (rounds 1 and 2 combined), and your cumulative point total for the current sequence. For your convenience, on each decision screen you will see a history of your decisions in prior rounds of the Decentralized Meeting (DM) or the Centralized Meeting (CM).

Determination of your Earnings

At the end of the first part of today's session, your point total from all sequences played, including the initial 20 points you were given at the start of the experiment, will be converted into dollars at the rate of 1 point = $0.30. You will have a chance to earn additional payments in the second part of today's session.

Summary

1. You start with 20 points. You will play a number of sequences each consisting of an unknown number of periods. Your point total accumulates over all sequences.
2. Each period in a sequence consists of two rounds.

Round 1 Decentralized Meeting

i. Participants are randomly matched in pairs with one member of the pair randomly chosen to be the *Consumer* and the other chosen to be the *Producer*. Both roles are equally likely.
ii. Consumers decide how many units of a perishable good to request from the Producer with whom they are paired.
iii. Producers decide whether to accept or reject the proposal of their matched Consumer.
iv. If the proposal is accepted, the Consumer's point earnings are increased as in Table A1. The Producer's point earnings are decreased by the cost of producing the amount of the good agreed upon.
v. Participants are informed about the point earnings in their pair.

Round 2 Centralized Meeting

i. All participants interact together in the Centralized Meeting to decide whether to produce-and-sell, buy-and-consume or not participate in the market for a perishable good X.
ii. Participants who choose to produce-and-sell enter a quantity, q, of units they wish to produce for sale. Participants who enter a positive quantity $q > 0$ are then asked whether they would like to bid to buy-and-consume units of good X. A participant's bid b can be any amount between 0 and q, inclusive, where q is the quantity they offered to produce and sell of good X.
iii. The market price, P, of good X is determined as the ratio of the total amount bid for good X to the total amount of good X produced. If there are no bids (demand) for good X or no amount of good X produced (supply) then $P = 0$.
iv. If $P > 0$, each participant' Centralized Meeting points are determined by the formula: $-q + b/P$. If $P = 0$, there is no market for good X and all participants earn 0 points from the Centralized Meeting.
v. Participants are informed of the market price, P, and about their own Centralized Meeting point earnings (if any).

3. At the end of each 2-round period, a number (integer) from 1 to 6 is randomly drawn and determines whether the sequence continues with another 2-round period. If a 1,2,3,4, or 5 is drawn the sequence continues. If a 6 is drawn, the sequence ends. Thus, there is a 5/6 chance that a sequence continues and a 1/6 chance that it ends.
4. If a sequence continues, then a new period begins. Point balances carry over from the end of the prior period and participants are randomly

paired anew in the Decentralized Meeting (round 1) of the new period. If a sequence ends, then depending on the time available, a new sequence may begin.

5. Points accumulate over all sequences. At the end of the session, each participant's cumulative point total from this first part of the session will be converted into cash at the rate of 1 point = \$0.30.

Questions?

Now is the time for questions about these instructions. If you have a question, please raise your hand and an experimenter will come to you.

Quiz

Before we start, we would like you to answer a few questions that are meant to review the rules of today's experiment. The numbers that appear in these questions are for illustration purposes only; the actual numbers in the experiment may be different. When you are done answering these questions, raise your hand and an experimenter will check your answers.

1. How many rounds are there in each period?_______
2. Suppose it is period 2 of a sequence. What is the probability that the sequence continues with a period 3? _______ Would your answer be any different if we replaced period 2 with period 12 and period 3 with period 13? Circle one: yes/no.
3. Can you choose whether you are a producer or consumer in the first round of a period, that is, the Decentralized Meeting?_______
4. Can you choose whether you are a producer/seller or buyer/consumer in the second round of a period, that is, the Centralized Meeting?_______
5. Suppose in the Decentralized Meeting that you are the Consumer. You propose that the producer produce two units of the perishable good and the Producer accepts your proposal.
   a. What are your additional point earnings this round? (Use Table A1) _______
   b. How many points does it cost the Producer for agreeing to your proposal? (Use Table A1)_______
6. Suppose that in the Centralized Meeting you offered to produce and sell $q = 4$ units and you bid $b = 1$ to buy and consume units of good X. After

all participants have made their decisions, it turns out that the market price, $P = 1/2$.

a. How many points does it cost you to produce and sell the four units? (Use Table A2)_______
b. How many units of good X were you able to buy-and-consume with your bid of 1? (use the formula b/P) _______ How many points is this worth? (Use Table A2)
c. What are your total points from the Centralized meeting? (use the formula: $-q + b/P$) _______

7. Suppose that in the Centralized Meeting you offered to produce and sell $q = 5$ units and you bid $b = 5$ to buy and consume units of good X. After all participants have made their decisions, it turns out that the market price, $P = 1$.
   a. How many points does it cost you to produce and sell the five units? (Use Table A2) _______
   b. How many units of good X were you able to buy-and-consume with your bid of 5? (use the formula b/P) _______ How many points is this worth? (Use Table A2)
   c. What are your total points from the Centralized meeting? (use the formula: $-q + b/P$) ______
8. True or False: Your point total from all sequences played in this first part of the session will be converted into money and paid to you in cash at the end of the session. Circle one: True False.

Overview – Part 2

The second part of the experiment is exactly the same as the first part of the experiment in that there are 14 participants making consuming, producing, buying, or selling decisions in sequences of two-round periods. The probability a sequence continues from one period to the next remains 5/6 and you will also start this second part of the session with an endowment of 20 points. You earn or lose points each period according to the decisions you make, and your points earned from all sequences played in this second part will be converted into dollars at the same rate as before, with each point worth \$0.30.

The main change from the first part is that in this second part of the session each of the 14 participants will begin each new sequence of periods with an endowment of 8 "tokens." The total number of tokens ($14 \times 8 = 112$), is fixed for the duration of each sequence. Participants may choose whether or not to use tokens for exchange purposes as discussed below. Tokens have no value in terms of points.

As before in the first round of each new period, the 14 participants are randomly matched in seven pairs and make decisions with one another in a *Decentralized Meeting*. In the second and final round of each period, all 14 participants interact together in a *Centralized Meeting*. The tokens can be used in both the Decentralized and Centralized Meeting rounds as explained in the next two sections.

Round 1: Decentralized Meeting

As before participants are randomly paired. In each pair, one participant is randomly chosen to be the *Consumer* and the other is the *Producer*. At the start of each Decentralized Meeting round, you are equally likely to be assigned either role.

As before, the Consumer moves first. The Consumer is informed about his own token holdings as well as the token holdings of the matched Producer. Then the Consumer decides how many units of the perishable good they want their matched Producer to produce for them and how many tokens they are willing to give the Producer for this amount of goods – see Fig. A5. As before, Consumers can request any amount of the good between 0 and 22 units inclusive (fractions allowed) and can now offer to give the Producer between 0 and the maximum number of tokens they currently

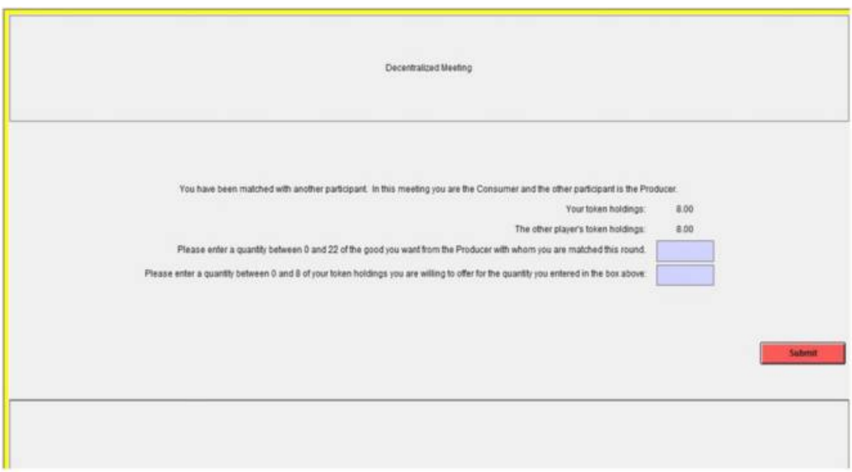

Fig. A5. Consumer's Decisions Screen, Decentralized Meeting.

have available, inclusive (fractions allowed). After all Consumers have made their decisions, Producers are informed of their own token holdings as well as the token holdings of their matched Consumer. Producers are then presented with their matched Consumer's proposal (amount of good requested and tokens offered in exchange). Producers must decide whether to "Accept" or "Reject" the Consumer's proposal – see Fig. A6. If a Producer clicks the Accept button, the proposed exchange takes place: the Producer produces the requested amount of the good and incurs a cost in points from doing so as given in Table A1, but now the Producer receives the amount of tokens, if any, the Consumer has offered in exchange. The Consumer receives a benefit in points from consumption of the amount of the good produced as indicated in Table A1 but loses any tokens offered to the Producer as part of the exchange. If the Producer clicks the Reject button, then no trade takes place: the token and point balances of both participants will remain unchanged.

After all decisions have been made the results of the Decentralized Meeting (round 1) are revealed. Any exchanges are implemented and we next move on to the Centralized Meeting – round 2.

Round 2: Centralized Meeting

In the second round of a period, all 14 participants again interact in a single Centralized Meeting. Each participant carries with him/her the token

Fig. A6. Producer's Decision Screen, Decentralized Meeting.

Fig. A7. Decision Screen for All Participants in the Centralized Meeting.

holdings that s/he had as of the end of round 1 (the Decentralized Meeting) *after* any exchanges have taken place in that round. In the Centralized Meeting, each participant now decides whether to (1) produce-and-sell units of the perishable "good *X*" in exchange for tokens, (2) use their tokens to bid for units of good *X*, (3) do both, or (4) do neither. The points you can earn from producing-and-selling or from buying-and-consuming units of good *X* are the same as in the first part and are given in Table A2. Notice that, differently from the first part, if you produce-and-sell units of good *X*, you incur costs in points according to Table A2, but you now receive tokens in exchange for any units you are able to sell. Also, to bid for units of Good *X* you now use your tokens and in exchange you receive units of Good *X* if you are able to buy such units (depending on supply and the market price as detailed below). The value of units of Good *X* is given in Table A2. The decision screen you face in the Centralized Meeting is shown in (Fig. A7).

You enter your produce-and-sell decision in the first box and the amount of your tokens you would like to bid for Good *X* in the second box. Note that you cannot bid more tokens than you have available. If you do not want to produce-and-sell units of Good *X* or if you do not want to bid your tokens for units of Good *X*, then enter 0 in the appropriate box(es).

After all participants have clicked the red submit button, the computer program calculates the total amount of good *X* that all participants have offered to produce and sell; call this: "Total Amount of Good X Produced." The program also calculates the total number of tokens bid toward buying units of good X by all participants; call this: "Total Amount of Tokens Bid for Good X." Finally the program calculates the *market price* of good X in terms of tokens as follows:

If Total Amount of Good X Produced > 0 *and* if Total Amount of Tokens Bid for Good $X > 0$, then the market price of good X, P, is determined by:

$$P = \frac{\text{Total Amount of Tokens Bid for Good } X}{\text{Total Amount of Good } X \text{ Produced}}$$

If Total Amount of Good X Produced $= 0$ *or* if Total Amount of Tokens Bid for Good $X = 0$ (*or both* are equal to 0), then $P = 0$.

Notice that you do not know the value of P when deciding whether to produce or bid tokens for units of good X; P is determined only *after* all participants have made their Centralized Meeting decisions. Once the market price, P, is determined, if $P > 0$ then individuals who participated in the Centralized Meeting earn points according to the formula:

$$\text{Centralized Meeting payoff in points} = -q + b/P \tag{A.2}$$

The first term, $-q$, represents the cost to you of producing and selling q units of good X. The second term, b/P, represents the number of units good X you were able to *buy and consume* given your bid of b tokens and the market-determined price, P. In addition, if $P > 0$, each individual who participated in the Centralized Meeting will see their own token balance adjusted as follows:

$$\text{New Token Balance} = \text{Old Token Balance} + Pq - b \tag{A.3}$$

Notice several things. First, if $-q + b/P$ is negative (equivalently, if $Pq - b$ is positive[17]), so that you are a *net seller* of good X, then you lose points from the Centralized Meeting according to the formula (A.2). However, at the same time, your new token balance increases relative to your old token balance by the positive amount $Pq - b$ according to the formula (A.3). Second, if $-q + b/P$ is positive (equivalently, if $Pq - b$ is negative) so that you are a *net buyer* of good X, then you earn additional points from the Centralized Meeting according to formula (A.2). However, at the same time, your new token balance decreases relative to your old token balance by the negative amount $Pq - b$ according to formula (A.3). Thus, if $P > 0$, those who are net *seller-producers* of good X will leave the Centralized Meeting with *higher* token balances but with *lower* point totals, while those who are net *buyer-consumers* of good X will leave the Centralized Meeting with *lower* token balances but with *higher* point totals. Finally, note that if $P = 0$, or if you do not produce or bid tokens for good X in the Centralized Meeting, then your point and token balances remain unchanged.

Players' new (or unchanged) token balances and point totals will carry over to the Decentralized Meeting of the next period of the sequence, if there is a next period, which depends on the random number drawn. If the sequence does not continue with a new period, then all participants' token balances are set to zero, and their point totals for the sequence are final. Depending on the time available, a new sequence may then begin. At the beginning of each new sequence, each participant is given eight tokens.

Information

After each round, participants will be informed about their point totals and their token holdings. After round 1 (Decentralized Meeting) participants will also be informed about the point totals and the token holdings of the participant they were paired with. All interactions remain anonymous. After round 2 (Centralized Meeting) you will see your token and point totals both for the Decentralized Meeting round 1, the Centralized Meeting round 2, the period (rounds 1 and 2 combined), and your cumulative point total for the current sequence. For your convenience, on each decision screen you will see a history of your decisions in prior rounds of the Decentralized Meeting (DM) or the Centralized Meeting (CM).

Determination of your Earnings

At the end of this second part of today's session, your point total from all sequences played, including the initial 20 points you were given at the start of this second part, will be converted into dollars at the rate of 1 point = \$0.30. You will be paid your total earnings from the first and second parts of today's session plus a \$5 show-up payment in cash and in private.

Summary

Part 2 is the same as part 1 except that:

- Each player starts each new sequence with eight tokens. The total supply of tokens remains constant at $14 \times 8 = 112$ tokens over all rounds of a sequence. Tokens have no value in terms of points.
- In the DM, Consumers' proposals now include both an amount of the good the Producer is asked to produce *and* an amount of tokens the Consumer offers to give the Producer in exchange. As before, Producers can either accept or reject the Consumer's proposal.
- In the CM, all 14 participants meet and individually decide whether to produce and sell units of Good X in exchange for tokens and/or to bid their available tokens for units of Good X. All sales of units of Good X for tokens are at the single market-determined price, P.

In all other respects, this second part of the experiment is the same as the first part.

Questions?

Now is the time for questions about these instructions. If you have a question, please raise your hand and an experimenter will come to you.