The Friedman Rule: Experimental Evidence*

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Abstract

We explore the celebrated Friedman rule for optimal monetary policy in the context of a laboratory economy based on the Lagos-Wright model. The rule that Friedman proposed can be shown to be optimal in a wide variety of different monetary models, including the Lagos-Wright model. However, we are not aware of any prior empirical evidence evaluating the welfare consequences of the Friedman rule. We explore two implementations of the Friedman rule in the laboratory. The first is based on a deflationary monetary policy where the money supply contracts to offset time discounting. The second implementation pays interest on money removing the private marginal cost from holding money. We explore the welfare consequences of these two theoretically equivalent implementations of the Friedman Rule and compare results with two other policy regimes, a constant money supply regime and another regime advocated by Friedman, where the supply of money grows at a constant k-percent rate. We find that, counter to theory, the Friedman rule is not welfare improving, performing no better than a constant money regime. By one welfare measure, we find that the k-percent money growth rate regime performs best.

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1 Introduction

Friedman (1969) argued that the welfare maximizing monetary policy is one that eliminates incentives to economize on the use of money. One way to achieve this goal is to choose inflation so that the nominal interest rate is equal to zero. Since the nominal interest rate represents the private marginal cost of holding money, and the marginal cost of producing money is essentially zero, if the private marginal cost were positive, there would be an inefficient gap that could be closed by making the nominal interest rate equal to zero.

The Friedman rule "is undoubtedly one of the most celebrated propositions in modern monetary theory, probably *the* most celebrated proposition in what one might call "pure" monetary theory..." (Woodford, 1990). Indeed, the Friedman rule has played such an important role in monetary theory that we believe it is deserving of an empirical evaluation.

Since central bankers are reluctant to conduct experiments in the field for a variety of reasons, we perform the exercise in the laboratory, where we are not so restricted by conventional wisdom or by fears of possible policy effects on macroeconomic performance.[1] We are not aware of any prior test of the Friedman rule in the lab or in the field. In addition to two different implementations of the Friedman rule, we consider a constant money supply rule and a k-percent money growth rate rule. Our larger aim is to demonstrate that laboratory tests of monetary policies could be a complementary tool to theory and empirical analysis of field data in the evaluation of different monetary policies.

Our framework for monetary policy analysis is the Lagos and Wright (2005) search-theoretic model of money, in which the Friedman rule is the optimal monetary policy. We choose to work with this framework for several reasons. The Lagos-Wright model is a work-horse model in monetary economics and it is amenable to laboratory implementations. Specifically, it is an explicitly micro-founded, dynamic search model of money with many desirable features: there is anonymous pairwise matching and lack of commitment, monitoring and record-keeping so that money plays an essential role. That is, this model is explicit about why and how money is used in the economy. Periodic access to competitive markets and quasi-linear preferences enable agents to re-balance their money holdings following pairwise meetings ensuring that the model is tractable, even when goods and money are divisible and without upper bounds on the amount of money holdings.[2] Importantly, the Lagos-Wright model's explicit dynamic structure provides us with precise welfare measures that enable us to evaluate the impact of different monetary policies in our analysis of experimental data.

[1] While central bankers are undoubtedly aware of the Friedman rule and often express a genuine desire for low inflation, it would be very much against conventional wisdom for central bankers to argue for, let alone attempt to implement, a negative inflation rate as the Friedman rule would require in its most commonly known implementations. One reason for this reluctance is that deflation is thought to be associated with negative economic growth and depression. However, as Atkeson and Kehoe (2004) show using a sample of data from 17 countries over 1820-2000, there is "virtually no link between deflation and depression." Indeed, Uhlig (2000) interprets liquidity traps involving near zero interest rates as potentially benign implementations of the Friedman rule. Williamson (2012) and Rocheteau, Wright and Xiao (2018) show that liquidity traps and the Friedman rule are different phenomena. A second reason is that a deflationary monetary policy in a less–than–perfectly-flexible-price world seems likely to generate welfare costs that the theoretical models giving rise to the Friedman rule as the optimal policy prescription ignore. However, even in models with sticky prices and money demand, the optimal policy has been shown to involve an inflation rate that lies somewhere between the Friedman rule (deflation) and 0, see, e.g., Khan, King, and Wolman (2003), Schmitt-Grohé and Uribe (2004) and Aruoba and Schorfheide (2011).

[2] See Williamson and Wright (2010ab) and Lagos et al. (2017) for arguments in favor of using such "New Monetarist" models to understand monetary policy. This literature follows Wallace's dictum (1998) that "money should not be a primitive in monetary economics."

Without such an explicit, micro-founded framework it would not be possible to assess whether the Friedman rule was welfare-maximizing.

The rule that Friedman proposed can be shown to be optimal in a wide variety of different monetary models, including the Lagos-Wright model that we use in our experiment. Walsh (2010) provides a discussion of other monetary models and the conditions under which the Friedman rule is the optimal policy in those models. We prefer the Lagos-Wright model over these other monetary models for the purpose of our study. Specifically, New Keynesian models are for the most part cashless and the Friedman rule seeks to offset the opportunity cost of holding cash balances. Cash-in-advance/money-in-the-utility function models assume that fiat money has value. Finally, in overlapping generations models, the Friedman rule is not necessarily optimal.

Friedman (1969) proposed two ways of implementing his optimal monetary policy rule. The first is to follow a deflationary monetary policy. If the real rate of return on safe government bonds is $\rho > 0$, and the nominal interest rate, i, as given by the Fisher equation, is $i = \pi + \rho$, where π denotes the expected inflation rate, then, in order to have $i = 0$ the central bank' monetary policy should be to set $\pi = -\rho < 0$, that is to implement a deflationary policy. A second, alternative approach is simply to pay a competitive market interest rate on money holdings removing altogether the private marginal cost from holding money. As with the first approach, the difficulties of providing interest on cash holdings has likely rendered this possibility impractical (though the U.S. Federal Reserve has paid interest on bank reserves since October 2008). In this paper we explore, for the first time, *both* implementations of the Friedman rule in our experimental Lagos-Wright economy.[3]

We compare these two versions of the Friedman rule with two other monetary policy regimes. The first is a constant money supply regime which serves as our control treatment. The second is a constant money growth rate regime where the money supply grows at a fixed and known k-percent per period. Such a regime was also advocated by Friedman (1960, 1968), who understood well that a constant money growth rate was not the optimal monetary policy regime in the "simple hypothetical economy" of his model. Friedman advocated for a constant money growth rate rule because he thought that such a policy was better in practice than discretionary monetary policies aimed at stabilizing business cycle fluctuations:

> "There is little to be said in theory for the rule that the money supply should grow at a constant rate. The case for it is entirely that it would work in practice." (Friedman 1960, p. 98)

To preview our experimental results, we find that the Friedman rule, as implemented using either a deflationary policy or via the payment of interest on money holdings, does not result in any welfare improvement relative to a constant money supply regime. Indeed, we find that by one measure of welfare, there are welfare gains from pursuing an *inflationary* monetary policy where the money supply grows at a constant k percent. We discuss several possible explanations for our findings, which are at odds with theoretical predictions. In particular, we suggest that liquidity constraints and precautionary motives associated with lump-sum taxation may explain the lower welfare achieved under the Friedman rule policy regimes relative to the inflationary policy regime.

[3] We conjecture that this has not been done in prior work due to challenges associated with the implementation of lump-sum taxation. We explain what these challenges are and how we overcome them in Section 4.1.

2 Related Literature

There are some experiments that have considered the impact of monetary policies primarily on expectations of inflation and/or the output gap or for the stability of prices. Some of these studies also have subjects play the role of central bankers. See, for example, Arifovic and Sargent (2003), Arifovic and Petersen (2017), Assenza et al. (2019), Bernasconi and Kirchkamp (2000), Cornand and M'baye (2018), Deck et al. (2006), Duffy and Heinemann (2019), Fenig et al. (2018), Hommes et al. (2019), Kryvtsov and Petersen (2020), Jiang et al. (2019), Marimon and Sunder (1993, 1994, 1995), Petersen (2015), and Pfajfar and Žakelj (2016, 2018).

None of these experiments have implemented a monetary policy that was optimal for the environment studied. Further, we are not aware of any prior experimental test of Friedman's optimal deflationary policy or alternative implementations of that policy such as the payment of interest on money holdings, and these are the dimensions that set our study apart from other experimental studies of monetary policy.

The Lagos and Wright model that we use is one that we have previously studied in the laboratory, with the aim of understanding the welfare consequences of having a fiat money object versus the case where no such money object exists; see Duffy and Puzzello (2014a). Monetary policy was not considered in that experiment; indeed, in the case where there was a money supply, the stock of money was held constant. Thus, while in this paper we implement a similar framework, we focus on questions of *monetary policy* and in the process we overcome new design challenges that we did not face in our previous work (e.g., implementation of lump-sum taxation).[4]

In the finite population version of the Lagos-Wright economy that we studied, there exists a continuum of non-monetary 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., Araujo (2004), Aliprantis et al. (2007ab), Araujo et al. (2012)). However, we found that subjects avoid non-monetary 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. (2007) 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.

In subsequent work (Duffy and Puzzello 2014b) we studied whether subjects would come to adopt a fiat money for exchange purposes if they initially participated in a Lagos-Wright economy without fiat money (gift-exchange only). We also studied the reverse scenario where subjects initially experienced a Lagos-Wright economy with a constant supply of fiat money and then were placed in an economy where only gift–exchange was allowed (fiat money was taken away). We found that when subjects began in the setting without fiat money, they again coordinated on low-welfare gift exchange equilibria. When fiat money was introduced (without any legal restriction on its use), subjects adopted it in exchange, but there was no improvement in real activity or welfare.

[4] It is not unusual, both in theory and experiments, to use similar frameworks to address different questions. For example, there is a large theoretical literature employing the Lagos-Wright model to address many questions in macroeconomics (e.g., see Lagos et al. (2017), Rocheteau and Nosal (2017), or Williamson and Wright (2010a, 2010b)). Similarly, the framework proposed by Smith et al. (1988) has been extensively used in experimental economics to study bubble formation and asset price anomalies in laboratory asset markets. Further, many social dilemma games (Prisoner's Dilemma or Voluntary Contribution Mechanism Public Goods games) or bargaining games have been repeatedly explored in a number of important papers in experimental economics.

By contrast, when subjects began in the setting with fiat money, they again coordinated on a more efficient monetary equilibrium but when fiat money was taken away, real exchange activity markedly declined along with welfare. We further studied the case where the fixed supply of fiat money was doubled or halved. Our aim was to study the neutrality of money proposition. We found that in the case where the fixed supply of money was doubled, prices approximately doubled and real quantities did not change in line with the neutrality proposition. However, in the case where the fixed supply of fiat money was cut in half, prices did not adjust downward and there were real welfare losses.

Camera and Casari (2013, 2014) also compare outcomes across two environments, with fiat money ("tickets") and without fiat money. In their dynamic game, money is not essential to achieve the Pareto efficient outcome which can be supported instead by social norms. However, they find that the introduction of fiat money helps to support cooperation and more so in larger groups. Davis et al. (2019) study *finite horizon* environments with and without fiat money. They study how fiat money affects allocations both in environments where monetary exchange is an equilibrium and where it is not. They find that fiat money tends to promote efficiency in all environments, regardless of whether there is a monetary equilibrium. Jiang and Zhang (2018), Ding and Puzzello (2020), and Rietz (2019) study currency competition in search models with two currencies. In these studies, the money supply is constant and so there is no inflation or deflation.

Finally, Anbarci et al. (2015) study the effect of an inflation tax in the context of the Lagos-Wright model using Burdett, Shi and Wright's (2001) price-posting framework. They report that, in their experiment – as in the model – inflation works as a tax as it reduces real prices, cash holdings, GDP and welfare. Moreover they find that the effect of the inflation tax on welfare is relatively greater at low levels of inflation than at higher levels.

3 Theoretical Framework

In this section, we present the most general theoretical framework that guided our experimental implementation. The theoretical framework is based on the Lagos and Wright (2005) model, a microfounded model of money sufficiently tractable to be integrated with mainstream macroeconomics. We discuss the baseline economy as well as the three different monetary policy regimes that we also implement as distinct treatments. It is well-known that there is an autarkic equilibrium where money has no value. We focus on the monetary equilibrium where fiat money is valued. In what follows, we describe the economic environment and the optimization problem characterizing the monetary equilibrium solution. More details are provided in Appendix A, Lagos and Wright (2005) or Rocheteau and Nosal (2017).[5]

There are $2N$ infinitely-lived agents who discount the future with discount factor $\beta \in (0,1)$. Periods are dated t = 1,2,... Each agent enters a period holding some non-negative amount of an intrinsically worthless and inconvertible object referred to as fiat money, which is both divisible and durable. Let $\left(m_t^1, m_t^2, ..., m_t^{2N}\right)$ denote the distribution of money holdings at the beginning of period t, where m_t^i denotes the money holdings of agent i at the beginning of period t. The initial money supply is given by $\sum_{i=1}^{2N} m_1^i = M_1$.

Each period t consists of two rounds. In the first round (decentralized market, DM), agents are randomly (uniformly) and bilaterally matched and an agent in each pair is randomly chosen

[5]See also Lagos, Rocheteau and Wright (2017) for a discussion of the advantages of this framework.

to be the producer or the consumer of the DM good with equal probability. In the DM, each consumer proposes terms of trade, q_t and d_t, denoting, the quantity of the DM good requested from the producer and the amount of money the consumer will give the producer in exchange (up to the limit of the consumer's current money holdings) in period t. The producers' choice is to accept or reject these proposed terms of trade. Acceptance involves paying a cost, $c(q_t)$, to produce the requested quantity but receiving d_t units of money in exchange. In the case of rejection, no trade/production takes place and the money holdings of both players are unchanged.

In the second round (centralized market, CM) agents decide on consumption and production of the CM good X and their fiat money savings (or equivalently how much money to carry over to the next decentralized market round). That is, they decide how much to sell or buy in the Walrasian market in order to rebalance their money holdings. The combination of DM and CM markets captures the idea that in some markets it is easier to trade and find a counterparty than in other markets. Goods are divisible but perishable.

Let ϕ_t denote the price of money in terms of the CM good in the centralized market in period t. Also, let $\varphi : A \twoheadrightarrow A$ be an exhaustive bilateral matching rule, so that no agent remains unmatched.[6] Let M_t denote the total stock of fiat money at the beginning of the centralized market in period t prior to any injection or withdrawal. Assume that this stock expands at the gross rate μ so that $M_{t+1} = \mu M_t$, where M_{t+1} denotes next period money supply. Money is injected or withdrawn by way of a lump-sum transfer or tax τ_t levied on agents at the end of the CM. Suppose that the government can pay interest, i_m, on money holdings at the beginning of the CM. In each period t, the government budget constraint is given by $2N\tau_t + i_m M_t = M_{t+1} - M_t$, or $2N\tau_t + i_m M_t = (\mu - 1) M_t$. We denote by x and y consumption and production of the DM good during the first round, and by X and Y production and consumption of the CM good in the second round. Period preferences are given by $U(x, y, X, Y) = u(x) - c(y) + X - Y$, where u and c are twice continuously differentiable with $u' > 0$, $u'' < 0$, $c' > 0$, $c'' \geq 0$. There exists a $q^* \in (0, \infty)$ such that $u'(q^*) = c'(q^*)$, i.e., q^* is efficient as it maximizes surplus in a pair. Also, let $\bar{q} > 0$ be such that $u(\bar{q}) = c(\bar{q})$.

The periodic access to the centralized market in conjunction with the quasilinearity of preferences deliver tractability and thus a closed-form solution for the monetary equilibrium. Following the same steps as in Lagos and Wright (2005) (see also Appendix A), given the quasi-linearity assumption and take-it-or-leave-it trading protocol,[7] the amount of money carried over from the centralized to the decentralized market (or savings), m^i_{t+1}, solves a sequence of simple static optimization problems:

$$\underset{m^i_{t+1}}{Max} \left\{ -(\phi_t - \beta(1+i_m)\phi_{t+1})m^i_{t+1} + \beta\frac{1}{2}\left[u(q_{t+1}(m^i_{t+1}) - (1+i_m)\phi_{t+1}d_{t+1}(m^i_{t+1})\right] \right\}.$$

That is, the choice of how much money to bring to the next DM, is governed by trading off the benefit (the liquidity return to money) given by $\beta\frac{1}{2}\left[u(q_{t+1}(m^i_{t+1}) - (1+i_m)\phi_{t+1}d_{t+1}(m^i_{t+1})\right]$ with the opportunity cost of holding money $-(\phi_t - \beta(1+i_m)\phi_{t+1})m^i_{t+1}$ associated with delayed consumption. Any equilibrium must satisfy $\phi_t \geq \beta(1+i_m)\phi_{t+1}$ or $\mu \geq \beta(1+i_m)$. Thus note that the minimum inflation rate consistent with an equilibrium involves $\frac{\phi_t}{\phi_{t+1}} = \mu = \beta(1+i_m)$, i.e., the Friedman rule. Also, note that under the Friedman rule, the opportunity cost of holding money is zero.

[6] An exhaustive bilateral matching rule is simply a function $\varphi : A \twoheadrightarrow A$ such that $\varphi(\varphi(a)) = a$ and $\varphi(a) \neq a$, for all $a \in A$. See also Aliprantis et al. (2007).

[7] The take-it-or-leave-it trading protocol delivers the most efficient allocation in the class of generalized Nash bargaining trading protocols.

The optimization problem described above delivers the following equation for the steady state monetary equilibrium solution:[8]

$$\frac{u'(\widetilde{q})}{c'(\widetilde{q})} = 1 + \frac{\mu - \beta(1 + i_m)}{\frac{\beta}{2}(1 + i_m)}. \tag{1}$$

Note that $\widetilde{q} \leq q^*$ since the function u'/c' is decreasing and $\mu \geq \beta(1 + i_m)$, and that $\widetilde{q} \to q^*$ as $\mu \to \beta(1 + i_m)$. The monetary steady state value function is given by $V = \frac{1}{1-\beta}\left\{\frac{1}{2}\left[u(\widetilde{q}) - c(\widetilde{q})\right]\right\}$.

3.1 Implementations of the Model

In the laboratory, we consider the following four implementations of the model.

1. Baseline-Constant M. In the baseline economy, money supply is constant ($\mu = 1$) and no interest is paid on money ($i_m = 0$). Therefore, since $\beta < 1$, it immediately follows from equation (1) that $\widetilde{q} < q^*$.

2. Friedman rule-FR-DFL. The first implementation of the Friedman rule is characterized by money supply contraction via lump-sum taxation and no interest payment on money ($i_m = 0$). Specifically, in order to achieve the first best q^*, we set $\mu = \beta$. Lump-sum taxes satisfy the budget constraint $2N\tau_t = (\mu - 1)\,M_t$. Clearly, from equation (1), the monetary equilibrium entails $\widetilde{q} = q^*$ under this policy.

3. Friedman rule-FR-IOM. The second implementation of the Friedman rule is characterized by interest payment on money (financed via lump-sum taxes) and constant money supply, i.e., $\mu = \beta(1 + i_m) = 1$. Lump-sum taxes must then be equal to the interest payment $2N\tau_t = -i_m M_t$. As in FR-DFL, from equation (1), the monetary equilibrium DM quantity is $\widetilde{q} = q^*$ under this policy.[9]

4. $k-$percent rule-k-PCT. In this implementation, we consider an inflationary monetary policy where the money supply growth rate is fixed and publicly announced and no interest is paid on money ($i_m = 0$). Money supply growth is achieved via lump-sum transfers at the end of the CM. Since $\mu > 1$, from equation (1), the monetary equilibrium quantity achieved under this policy is lower than in the baseline economy.

Note that all four regimes can be viewed as various types of k-percent rule regimes, with the FR-DFL regime having a negative k, the Constant-M and FR-IOM regimes having $k = 0$ and the k-PCT regime having a positive k (equal to the absolute value of the FR-DFL k value).

[8]See also Rocheteau and Nosal (2017).

[9]We consider just these two classic implementations of the Friedman rule (as proposed by Friedman himself). For other implementations of the Friedman rule in the context of search models see Andolfatto (2010) and Lagos (2010). For example, Lagos (2010) characterizes a large family of monetary policies that implement Friedman's rule in a monetary search economy with fiat money, equity and aggregate uncertainty. The family of optimal policies satisfies two properties: (i) the money supply must be arbitrarily close to zero for an infinite number of dates, and (ii) asymptotically, on average over the dates when fiat money plays an essential role, the growth rate of the money supply must be at least as large as the rate of time preference. The money contraction process we consider here, $M_t = \beta^t M_0$ satisfies these conditions. Other processes that satisfy these conditions are $M_t = \gamma^t M_0$ for γ in $[\beta, 1)$ or $M_t = \gamma^t[1 + b * \sin(t)]M_0$ for γ in $[\beta, 1)$ and b small.

3.2 Hypotheses

Based on the theoretical model, we formulate the following hypotheses that we will test using our experimental data. Assuming that individuals seek efficient outcomes, we conjecture that they will coordinate on the monetary rather than the autarkic equilibrium:

Hypothesis 1 *The monetary equilibrium rather than the autarkic outcome better characterizes trading behavior.*

Consistent with Friedman's theory of the optimal quantity of money, we have:

Hypothesis 2 *Quantities traded and welfare are higher under either Friedman rule treatment, FR-DFL or FR-IOM, as compared with the baseline Constant M treatment.*

Further, the manner in which the optimal policy is implemented should not matter:

Hypothesis 3 *There is no difference in quantities traded or welfare between the two Friedman rule treatments, FR-DFL or FR-IOM.*

Since we study an economy without growth, inflationary monetary policy should be worse than a regime where the money supply remains constant as inflation acts like a tax on real balances.

Hypothesis 4 *Quantities traded and welfare are lower under the k-percent treatment as compared with the baseline Constant M treatment.*

Price levels in both the DM and CM should reflect the monetary policy regime that is in place.

Hypothesis 5 *Prices in either the DM or CM should be highest under the k-percent policy rule and lowest under either Friedman rule.*

Finally, consistent with the quantity theory of money, the rate of change of prices should be equal to the rate of change of the money supply.

Hypothesis 6 *There is inflation of the price level over time under the k-percent regime, deflation of the price level over time under the FR-DFL and no change in the price level over time in the Constant M or FR-IOM treatments.*

4 Experimental Design

Our experiment involves four treatments, all of which use the Lagos-Wright (2005) economy in a laboratory setting. We first discuss how we implement the baseline, constant money supply treatment before discussing the other three treatment variations.

Each session of the baseline treatment involves $2N$ players or subjects who participate in a number of "sequences" or supergames. At the start of each new sequence all subjects are endowed with $M/2N$ "tokens," our name for fiat money, and a fixed number of points, $\mathcal{P}$. Subjects are instructed that tokens, in keeping with fiat money, have no redemption value (intrinsic value); only their point totals matter for final payoffs. Each sequence consists of an indefinite number of periods.

Each period involves two rounds of decision-making: the decentralized market (DM) round and the centralized market (CM) round.

In the first decentralized market (DM) round, all $2N$ subjects are randomly and anonymously paired with one another to form N pairs. One subject in each pair is randomly chosen to be the consumer and the other is the producer; subjects are instructed that their chance of being the consumer (producer) in each DM round is 50 percent. Each consumer i moves first, making a proposal of $\{q_i,\ d_i\}$, where q_i is the amount of the special good that consumer i requests his matched producer to produce and d_i is the amount of fiat money that i offers the producer in exchange. We restrict $0 \leq q_i \leq \overline{q}$ and $0 \leq d_i \leq d_i^{DM}$, where $\overline{q}$ is an upper bound on exchange and d_i^{DM} is i's initial DM money holdings. Producer j moves second, by either accepting or rejecting his matched consumer i's proposal. If a proposal is accepted, it is immediately implemented. The consumer acquires q_i units of the DM good, earning $u(q_i)$ points that get added to the consumer's point total, but gives away d_i tokens (units of money). The producer incurs a production cost of $c(q_i)$ points that is subtracted from the producer's point total, but acquires an additional d_i tokens (units of money) as part of the exchange. If the producer does not agree to the consumer's proposal, then no trade takes place and DM earnings are 0 points for both the consumer and producer.

In the second centralized market (CM) round, all $2N$ subjects meet together to participate in a market for a homogeneous good "X." The purpose of the CM meeting is to allow re-balancing of money holdings. As in Duffy and Puzzello (2014a), the market for the homogeneous good X is implemented using a Shapley-Shubik (1977) market game.[10] Specifically, subjects can choose to be either buyers or sellers of good X. If player i chooses to be a buyer, s/he specifies an amount of tokens, b_i, to bid toward units of good X subject to $0 \leq b_i \leq d_i^{CM}$ where d_i^{CM} is i's initial CM money holdings (following any DM exchanges). If player i chooses to be a seller, s/he specifies the number of units of good X, Q_i s/he is willing to produce. We assume linear benefits and costs in the CM market in keeping with the quasi-linear specification for preferences. That is, the utility benefit of one unit of good X, $U(X)$, is 1 point and the cost of producing one unit of good X, $C(X)$, is also 1 point. The centralized market price of good X is determined by:

$$P = \frac{\sum_i b_i}{\sum_i Q_i}.$$

All exchanges take place at this market clearing price. If there are no bids or no supply of good X, then there is no market price and no centralized market exchange. Following completion of the CM market, money balances and points are adjusted according to the CM outcome and the CM market round ends. Successful buyers of good X earn $U(b_i/P) = b_i/P$ points, and sellers of good X earn $-Q_i$ points.

Following the completion of the CM round, a random number (an integer) is drawn from the set $\{1, ..., 6\}$ to determine whether the sequence continues with another two-round period.

If the random number drawn is less than 6, then the sequence continues; subjects' point and token balances carry over to the next two-round period. Otherwise, the sequence ends, point balances are final and token balances are zeroed-out. The random continuation of each sequence with

[10] While Lagos and Wright (2005) model the CM as a Walrasian market, we chose to implement the CM market using a market game, as it provides non-cooperative game theoretic foundations for price taking behavior in sufficiently large populations. As Duffy, Matros, and Temzelides (2011) report, groups of size 20 act like price takers and the resulting outcomes are in line with the unique competitive equilibrium of the associated pure exchange economy they study. On the other hand, smaller groups of size 4 are closer to a Nash equilibrium prediction that differs from the competitive equilibrium. We also think it is desirable to have prices endogenously determined.

probability $\beta = 5/6$ is a commonly used way to implement both discounting and the stationarity associated with an infinite horizon.[11] Depending on the time remaining in the session, a new sequence may be then played. Subjects would begin each new sequence with $M/2N$ tokens and $\mathcal{P}$ points. At the end of the session following completion of the final supergame, subjects are paid their point totals from all sequences played.

4.1 Friedman Rule Treatments

Our two Friedman rule treatments modify the baseline constant money treatment (described in the last section). In the first implementation of the Friedman rule, known as the Friedman Rule Deflation (FR-DFL) treatment, we contract the aggregate money supply by the amount $(1-\beta)M$ at the end of each two-round period, following completion of the CM market and execution of all exchanges from that market. The money supply reduction is implemented by reducing all subjects' money holdings so that in the aggregate, $M_{t+1} = \beta M_t$. Recall that $\mu = \beta$ is the optimal policy in the case where no interest is paid on money, i.e., where $i_m = 0$. The reduction is levied as a lump-sum tax on individual money holdings at the end of CM and would be applied to each individual's money holdings. By the government budget set and given $\mu = \beta$, it follows that $\tau_t = \frac{\beta-1}{2N}\beta^{t-1}M_1$ where M_1 is the initial money supply. Thus if subject i holds $d_{i,t}$ tokens following settlement of the CM, then, in the event that the sequence continues from period t to period $t+1$, this subject will have $d_{i,t+1} - \tau_t = d_{i,t+1} - \frac{\beta-1}{2N}\beta^{t-1}M_1$. In theory, reducing the money supply by the rate $\beta - 1$ per period will perfectly offset the time-delay risk associated with holding money so that the real return to holding money is constant and equal to the rate of time preference.

In the second implementation of the Friedman rule, known as the interest on money (FR-IOM) treatment, we pay an interest rate of i_m on money holdings held at the beginning of the CM following any DM exchanges. The interest payment is proportional to each subject's money holdings. Thus, if subject i has $d_{i,t}$ tokens after trades have occurred in the DM, then subject i's money holdings are increased to $(1+i_m)d_{i,t}$. Recall that in the FR-IOM treatment the optimal monetary policy is to set μ and i_m so that $\mu = \beta(1+i_m)$. If the policymaker wishes to achieve the first best without contracting the money supply, then the interest on money should be financed by some lump-sum transfers in addition to (possibly) money growth. The policy rule $\mu = \beta(1+i_m)$ together with the government's budget constraint implies that $2N\tau_t = (1+i_m)(\beta-1)M_t$, or $\tau_t = (1+i_m)(\beta-1)\frac{M_t}{2N}$. This tax rate is levied on agents' money balances following the completion of the CM market, after all exchanges have taken place in that market. Thus if subject i leaves the CM market with $d_{i,t}$ tokens, she will have $d_{i,t+1} = d_{i,t} - \tau_t = d_{i,t} - \frac{\beta-1}{2N}\beta^{t-1}(1+i_m)^t M_1$ tokens at the start of the next two-round period, if there is a next period. Notice that implicitly, the interest on money payments is being financed by a combination of an increase in the money supply or a tax on money holdings. In the experiment we set $\mu = 1$ so the interest on money payments is financed only by lump-sum taxes on money holdings. A challenging aspect associated with laboratory implementation of lump-sum taxation is: how to proceed if a subject does not have enough tokens to pay the tax? In this case, we engineered a procedure that would allow them to pay the tax in real terms. Specifically,

[11] The use of random termination to implement indefinite horizons begins with Roth and Murnighan (1978). Alternative approaches include finite horizon economies with final round coordination games that avoid unraveling due to backward induction (see, e.g., Cooper and Kühn (2014) and Fréchette and Yuksel (2017), Davis et al. (2019)). Jiang et al. (2021) consider three different implementations of an infinite horizon monetary economy and find that dynamic incentives are preserved in all. We see alternatives to the random termination method as more complicated to implement, and we did not want to add further complexity to our design.

"token poor" subjects were asked to produce units of the CM good at the most recently determined CM price in order to generate enough tokens to pay any tax shortfall. Effectively, these subjects were paying the tax in real terms.

The precise details of the FR-DFL and FR-IOM rules are clearly revealed to subjects, along with the timing of money injections or contractions. At the start of each sequence in a session, (round 1), subjects are endowed with $M_1/2N$ units of money and the policy rule is implemented beginning with round 2 and thereafter in all rounds of the sequence. The money stock is reinitialized at the start of each new sequence and the policy is implemented anew so that subjects gain experience with the consequences of the policy. The FR-DFL and FR-IOM treatments represent two alternative means of achieving the goal of a zero nominal interest rate, or in this case, compensating money holders for the time/risk delay of holding money. In our experiment the risk is that money (tokens) will cease to have value with probability $(1-\beta)$.

4.2 k-Percent Rule Treatment

Our final treatment involves the constant k-percent money rule, also advocated by Friedman, even though it is not theoretically optimal for the baseline economy. We implemented the k-percent rule (treatment k-PCT) by a lump-sum transfers of tokens at the end of the CM market. Specifically, we increased the total stock of money by k percent each period and distributed the additional tokens equally among all subjects. As in the other treatments, the precise details, including our choice for k, were clearly revealed to subjects, who were able to see that their token holdings were increasing at the end of each CM.

4.3 Parameterization and Predictions

The model was parameterized as follows. We set the discount factor (or the probability of continuation) at $\beta = 5/6$ (.83) as in our earlier work (Duffy and Puzzello 2014ab). The DM utility function is a CRRA function, $u(q) = 1.635\frac{q^{(1-0.224)}}{(1-0.224)}$. The DM cost function was linear, $c(q) = q$. These choices imply that the first best solution is:

$$q^* : u'(q^*) = c'(q^*) \Rightarrow q^* = 9.$$

By contrast, the monetary equilibrium solution in the DM of the baseline, constant money treatment, is given by:

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

We chose this parameterization for the model in order to make the difference between the first best and the monetary equilibrium solution sufficiently large so that we could detect which solution subjects were likely coordinating upon.[12] The utility and cost functions in the CM are both linear for simplicity.

We set the number of pairs in each session, $N = 7$. Further each of the $2N = 14$ subjects starts off with 10 tokens. Thus, the total stock of money in the first two-round period of every new sequence is $M_1 = 140$.

[12] In Duffy and Puzzello (2014ab) we set the DM utility function, $u(q) = 7\ln(1+q)$. With this choice, the first best solution, $q^* = 6$ while the monetary solution, $\tilde{q} = 4$, which are rather close to one another in levels and in welfare terms. For these reasons, we changed to the CRRA specification for $u(q)$ that we use in this paper.

In the deflation version of the Friedman rule (FR-DFL), at the end of each two-round period, the money stock is decreased at rate $\beta - 1$ or -16.67% per period which implies a deflation of the price level at the same rate. In the interest on money version of the Friedman rule (FR-IOM) we set $i_m = 0.20$ so that subjects earned 20 percent interest on their beginning of CM money balances; that is, interest earned was *proportional* to each subjects' beginning of CM token balance, d. The 20 percent interest rate choice was the solution to $\mu = 1 = \beta(1 + i_m)$, using our choice for $\beta = 5/6$. The revenue needed to cover this 20 percent interest payment was provided by a *lump-sum tax* of 2 tokens per subject. The real effects of monetary policy come from this lump-sum taxation scheme. In the end, the total stock of money in the FR-IOM treatment remains fixed at $M = 140$ (since $\mu = 1$) so there is neither inflation nor deflation of the price level in this treatment. Finally, in the constant, k-percent money growth treatment (k-PCT), we set $k = 1 - \beta$ so that the total stock of money increased by 16.67% per period. We chose this rate for symmetry with the constant deflation rate ($\beta - 1$) that was used in the first Friedman rule treatment, FR-DFL. Since $\beta = 5/6$ in the k-PCT treatment, the rate of inflation of the price level, by design, should be $1 - \beta$ or 16.67%.[13]

Given our parameterization of the model, the steady state predictions are provided in Table 1. Note that the first best quantity is only attainable in the two Friedman rule treatments, where

Table 1: Equilibrium predictions given our parameterization

Treatment	q	$P_{DM} = d/q$ (First Pd.)	$P_{CM} = \phi^{-1}$ (First Pd.)	Inflation Rate	Welfare	Welfare Relative to First Best
Const M	2	(10/2)=5	(10/2)=5	0	4.82	0.62
FR-DFL	9	(10/9)=1.11	(10/9)=1.11	−16.67%	7.78	1.00
FR-IOM	9	(10/9)=1.11	(10/9)(1.2)=1.33	0	7.78	1.00
k-PCT	0.65	(10/0.65)=15.38	(10/0.65)=15.38	16.67%	2.57	0.33

welfare is also predicted to be the highest across the four treatments.[14] Welfare is lowest in the k-percent monetary policy regime. The last two columns provide welfare comparisons in absolute terms as well as relative to the first best. Specifically, column six provides the expected lifetime payoff under each treatment. In column seven, we provide the welfare ratio relative to the first best, i.e., welfare normalized by the welfare level attained in the first best.

4.4 Procedures

The experiment was conducted over networked PCs using the zTree software (Fischbacher 2007). For each session we recruited 14 subjects with no prior experience with our experiment. The students were drawn from the undergraduate population of UC Irvine and were paid on the basis of their performance in the experiment.[15]

[13]The rate of inflation or deflation in our k-PCT and FR-DFL treatments may seem high by comparison with actual monetary policy practice. We purposely chose a high rate, 16.67%, in order to make the theoretical predictions discernible across our four treatments given the noisy nature of experimental data.

[14]Welfare is computed as expected discounted lifetime payoff, $(1/(1-\beta))(1/2)[u(q)-c(q)]$ using the parameterization of the model.

[15]There is evidence showing that student subjects behave similarly to professionals in a number of experiments comparing these two populations -see Fréchette (2015). More generally, monetary policies impact on students and

We employ a between subjects design where a single monetary policy regime is in effect for the duration of a session. At the start of each session, subjects were given written instructions which were also read aloud in an effort to make the instructions public information. The instructions for the FR-DFL treatment are provided in the online Appendix. Other instructions are similar.[16]

After the experimenter finished reading the instructions, subjects had to correctly answer a number of quiz questions testing their comprehension of the instructions. After all subjects had correctly answered all quiz questions, the experiment started. The instructional time took approximately 45 minutes.

Each session consisted of a number of sequences, with each sequence consisting of an indefinite number of periods. Subjects were instructed that a sequence would continue from one period to the next with probability $\beta = 5/6$ and would terminate with probability $1 - \beta = 1/6$.[17]

Subjects were not told the number of sequences that would be played. Instead, they were instructed "if a sequence ends, then depending on the time available, a new sequence will begin." In practice we let the program choose 5 realizations for the number of sequences and the lengths of those sequences. Then, we used the same realizations for the five sessions of each treatment to facilitate comparisons across treatments. The number of sequences and lengths are shown below in Table 2. Each session lasted approximately 2 hours and subjects were paid their earnings from all periods of all sequences played.

The common features of all four treatments were as follows:

Each subject was endowed with 20 points for the session. At the start of each sequence, each subject was endowed with 10 "tokens". Tokens had no redemption value in terms of points, so they were intrinsically worthless like fiat money. Token balances carried over from period to period but not from sequence to sequence. Subjects could use tokens to earn points and subjects' point balances carried over from period to period and across sequences. Subjects' final point balances from all sequences including their initial 20 point endowment were converted into dollars at a fixed rate of 1 point = \$0.40.

Each period consists two rounds. In the first round (the decentralized market (DM)), subjects were randomly and anonymously paired. In each pair, one member was randomly chosen to be the consumer and the other the producer. The consumer moved first, proposing an amount of the DM good that the matched producer would produce for the consumer and offering some number of tokens if the producer agreed to that proposal. Proposals for quantities of the DM good could range from 0 to 27 units of the DM good and consumers could offer between 0 and their current token balances in exchange.[18]

After viewing the consumer's proposal, the producer had to decide whether to accept it or not. If accepted, the proposal was implemented; the producer produced q units at a cost of $-q$ points and the consumer gained $u(q)$ points, but gave up d tokens to the producer. Adjusted token balances carried over to the next CM round.

In the CM round, subjects could choose whether to 1) produce the CM good X, 2) consume

professionals alike.

[16]The complete set of instructions can be found at `https://www.socsci.uci.edu/~duffy/MonetaryPolicy/`.

[17]We follow the interpretation of discount factor as probability of continuation, see Mailath and Samuelson (2006). See Fréchette and Yuksel (2017) for different implementations of infinite horizon economies in the context of infinitely repeated Prisoner's Dilemma games. Also, see Davis et al. (2019) for theory and experiments in finite horizon economies where money is valued.

[18]Beyond the upper bound of 27, $u(q)$ is always less than $c(q)$, so the surplus in a pair would be negative; this provides us with a natural upper bound for q

the CM good X, 3) do both, or 4) do neither. Each subject could choose to produce between 0 and 27 units of good X at cost of 1 point per unit produced and sold.[19] Each subject could also bid from 0 to the amount of tokens they carried over from the DM to buy and consume units of good X. The utility gain from a unit of good X was 1 point. Subjects were instructed that the CM price would be determined by the ratio of the sum of all bids to the sum of the quantity produced. Consumption of good X in terms of points was determined by the ratio of each subjects' bid divided by the single CM price, since the utility function in the CM round is linear.

At the end of each CM round, subjects learned their points for the period (from both the DM and CM), and their updated points for the sequence. Then, the realization of the random draw was revealed. If the number drawn was less than or equal to 5, the sequence continued with another period and subjects' token holdings carried over to the DM round of the new period. Otherwise if a 6 was drawn, the sequence ended.

The features that differed across treatments were as follows:

In the baseline, constant money treatment, the money supply remained constant at $14 \times 10 = 140$ tokens and this fact was public information.

In the Friedman rule - deflation treatment (FR-DFL), following the first period of each sequence, the total money supply was contracted via lump-sum "token taxes". This token tax collection followed the completion of the CM. Subjects were instructed that each period, the stock of tokens M would be reduced by 16.67%. The tax burden was shared equally according to a lump-sum tax. The per subject tax was computed for subjects by the computer program and a tax table was also provided for them. In the second implementation of the Friedman rule, FR-IOM, subjects received a proportional 20 percent interest on their token holdings at the beginning of the CM but were paying a lump-sum tax at the end of the CM. The interest payment and lump-sum taxes were chosen to keep the money supply constant. In the event that subjects did not have enough tokens to pay the tax, they were forced to produce units of the CM good at the most recently determined CM price in order to generate enough tokens to pay any tax shortfall. In the k-PCT treatment, following the first period of each sequence, the total money supply was expanded via lump-sum token transfers following the completion of the CM. Subjects were instructed that each period, the stock of tokens M would be increased by 16.67%. As in the FR-DFL treatment, the token transfer was computed for subjects by the computer program and a table listing lump-sum transfers was also provided for them.

5 Experimental Results

We report on data from five sessions each of our four treatments.[20] Each session involved 14 inexperienced subjects. Thus, we report on data from $5 \times 4 \times 14 = 280$ subjects. A summary of characteristics of our experimental sessions is provided in Table 2.

5.1 Proposals and Acceptance Rates

Table 3 reports on the average percentage of proposals involving positive tokens amounts and the average acceptance rates for such proposals per period, averaged over the first half, second half and

[19]We chose this upper bound for symmetry with the DM market, though utility is linear in the CM.

[20]We used theoretical predictions in conjunction with data from the closest treatment in Duffy and Puzzello (2014) to compute the power of the test for differences in quantities between the CM and FR treatments. For a sample size of 5 observations per treatment, the power is 96.33% (details available upon request).

Table 2: Characteristics of Experimental Sessions

Treatment	Obs No.	No. Seq.	Seq. Lengths	No. Rounds	Avg Earnings
Constant M	1	5	4,7,4,14,4	33	$22.73
Constant M	2	5	8,2,6,8,6	30	$22.61
Constant M	3	5	1,3,2,19,6	31	$21.43
Constant M	4	6	4,8,6,1,3,10	32	$24.02
Constant M	5	5	4,9,3,10,4	30	$22.00
FR-DFL	1	5	4,7,4,14,4	33	$25.00
FR-DFL	2	5	8,2,6,8,6	30	$21.00
FR-DFL	3	5	1,3,2,19,6	31	$22.00
FR-DFL	4	6	4,8,6,1,3,10	32	$26.57
FR-DFL	5	5	4,9,3,10,4	30	$22.86
FR-IOM	1	5	4,7,4,14,4	33	$22.47
FR-IOM	2	5	8,2,6,8,6	30	$18.02
FR-IOM	3	5	1,3,2,19,6	31	$22.17
FR-IOM	4	6	4,8,6,1,3,10	32	$20.25
FR-IOM	5	5	4,9,3,10,4	30	$21.58
k-PCT	1	5	4,7,4,14,4	33	$24.43
k-PCT	2	5	8,2,6,8,6	30	$27.98
k-PCT	3	5	1,3,2,19,6	31	$27.71
k-PCT	4	6	4,8,6,1,3,10	32	$21.39
k-PCT	5	5	4,9,3,10,4	30	$21.32

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all periods of each sequence, by treatment.[21]

Table 3: Average Percentage of Money Offers and Acceptance of those Offers, First Half, Second Half and All Periods of Each Sequence, by Treatment

	Percent Money Offers			Percent Accepted Money Offers		
Treatment	1st Half	2nd Half	All	1st Half	2nd Half	All
Constant M	95.50	87.34	91.41	43.34	36.91	40.32
FR-DFL	95.34	84.31	90.49	45.03	33.55	39.79
FR-IOM	94.39	85.19	90.27	49.16	41.61	45.80
k-PCT	98.81	98.22	98.53	44.95	35.72	40.29
Monetary Equ.	100	100	100	100	100	100

Note first that the monetary proposal average frequencies reported in Table 3 are all *conditional* on the consumer having positive token holdings.[22] Notice further that, over all periods, 90 percent

[21]In Table 3 we provide averages across sessions. Table C1 in Appendix C provides this same information at the session-level.

[22]Most consumers, between 84 - 100 percent on average across treatments, enter the DM with positive token

or more of DM proposals involve positive token amounts. Thus, it seems that subjects value tokens in exchange, despite the fact that these tokens have no redemption value and may become worthless. We conclude that there is support for Hypothesis 1; the monetary equilibrium is a better characterization of subject behavior than autarky. On the other hand, the acceptance rates of these money offers, as shown in columns 5–7, is less than 100 percent (as it would be in the monetary equilibrium). However, it is also the case that acceptance rates are not zero as they would be in an autarkic equilibrium. The roughly 40-50 percent acceptance rates of *money* offers that we observe in this experiment are in line with our earlier experimental results (Duffy and Puzzello (2014ab)) and are explained below by the offer terms that producers faced when deciding whether or not to accept consumers' offers (see Appendix C for a more detailed discussion of factors that may have contributed to relatively high rejection rates).[23]

Table 4 reports on the factors affecting producers' acceptance of money offers using a random effects probit regression with standard errors clustered at the subject level.[24] As this table reveals, producers are more likely to accept proposals involving a higher amount of tokens offered, d, and a lower amount for the producer to produce q (see specification 1). Alternatively, if the terms of trade as captured by the ratio d/q are better (specification 2) then producers are more likely to accept a consumer's offer. The money holdings of the consumer (m_c), or of the producer (m_p), do not seem to matter much for acceptance decisions, nor do there appear to be strongly significant treatment differences in producers' acceptance rates. Finally, there is some decay in acceptance rates over time within a sequence (SeqPeriod) but not at the start of each new sequence (NewSeq).

5.2 DM Quantities and Tokens Traded

Table 5 shows period average quantities and token amounts from accepted proposals in the decentralized markets over the first half, second half and all periods of each sequence, by treatment, along with equilibrium predictions (see Table C5 in the appendix for averages at the session level).[25] Relative to the theoretical predictions, the average *traded* quantities depart from the steady state values.

However, we can still consider whether average traded quantities conform qualitatively to treatment predictions. We find mixed support for Hypothesis 2. In particular, relative to the Constant M treatment, quantities in the FR-DFL treatment are on average slightly higher, but quantities in the FR-IOM treatment are essentially the same. Contrary to Hypothesis 4, quantities in the k-PCT treatment are higher than in the Constant M treatment. Inconsistent with Hypothesis 3, quantities in the FR-DFL version of the Friedman rule are on average slightly higher than in the

holdings. If we included consumers without any money holdings, we would find lower frequencies of money offers, particularly in the FR-DFL and FR-IOM treatments where more consumers entered the DM without tokens as compared with the other two treatments.

[23] Duffy and Puzzello (2014a) implemented also a version of TIOLI bargaining with multiple proposals stages. They observed higher acceptance rates with this implementation. They obtained similar results with this implementation as with the one with a single proposal. Since the implementation with multiple proposal stages would take more time and results appear to be robust, in the interest of collecting more data periods, we chose to use the implementation with a single proposal stage for this paper.

[24] We again restrict attention to proposals involving positive token amounts but the results reported in Table 4 are robust to including all offers.

[25] Since theory predicts that traded tokens decrease in FR-DFL and increase in k-PCT, we used the realized sequence lengths to compute predicted average tokens spent in the first half, second half and all periods of each sequence of every session; we report the average across sessions in Table 5.

Table 4: Random Effects Probit Regression Analysis of Acceptance of Money Offers

	(1) Accept Proposal	(2) Accept Proposal
Constant	0.339***	-0.079
	(0.090)	(0.089)
FR-DFL	0.136	0.032
	(0.109)	(0.111)
FR-IOM	0.163	0.183*
	(0.108)	(0.110)
k-PCT	-0.138	-0.172
	(0.109)	(0.110)
NewSeq	0.078	0.013
	(0.064)	(0.064)
SeqPeriod	-0.041***	-0.031***
	(0.008)	(0.008)
d	0.032***	
	(0.004)	
q	-0.092***	
	(0.006)	
d/q		0.135***
		(0.015)
m_c	-0.001	-0.008***
	(0.001)	(0.002)
m_p	-0.000	-0.000
	(0.001)	(0.001)
Observations	4017	3741
Log lik.	-2506.5	-2412.5
χ^2 stat.	264.4	107.6
Pr $> \chi^2$	0.000	0.000

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

FR-IOM version.[26]

[26] These findings are largely unchanged if we consider average *proposal* quantities rather than average *traded* quantities. Overall average *proposal* quantities were 5.25 in the Constant M treatment, 5.60 in the FR-DFL treatment, 4.49 in the FR-IOM treatment and 6.01 in the k-PCT treatment. While average proposal quantities are always greater than average traded quantities, they continue to depart from steady state values, and, relative to the Constant M treatment, display the same differences as is found using average traded quantities.

Table 5: Average DM Traded Quantities and Tokens, First Half, Second Half and All Periods of Each Sequence, by Treatment

	Average Traded Quantity			Average Traded Tokens		
Treatment	First Half	Second Half	All	First Half	Second Half	All
Constant M	3.96	3.39	3.70	4.93	4.93	4.91
Monetary Equ.	2	2	2	10	10	10
FR-DFL	4.96	2.89	4.04	3.14	1.57	2.44
Monetary Equ.	9	9	9	7.32	4.26	5.92
FR-IOM	4.13	3.15	3.67	4.54	3.44	4.03
Monetary Equ.	9	9	9	10	10	10
k-PCT	4.32	4.73	4.54	7.69	11.61	9.45
Monetary Equ.	0.65	0.65	0.65	12.70	30.65	22.65

A more formal analysis is provided in Figures 1-2 and in a regression analysis reported on in Table 6. Figure 1 shows mean DM traded quantities using data from all sessions of each of the four treatments along with 95 percent confidence intervals. Figure 2 does the same for mean DM traded tokens.[27] Consistent with the discussion above, DM traded quantity is significantly higher in the k-PCT treatment relative to the Constant M and FR-IOM treatments, but there is no significant difference between traded DM quantities in the FR-DFL and k-PCT treatments. DM traded tokens are consistent with the qualitative predictions of the theory: they are significantly highest in the k-PCT treatment, significantly lowest in the FR-DFL treatment, and intermediate in the Constant M and FR-IOM treatments, where they are not significantly different from one another.

Table 6 reports results from OLS regressions of traded DM quantities on dummies for the treatments FR-DFL, FR-IOM and k-PCT with standard errors clustered at the subject level; the baseline treatment is the Constant M treatment. The baseline DM quantity is shown to be around 4. We find that traded quantities are significantly greater by about 1 unit in the k-PCT treatment relative to the baseline Constant M treatment in contrast to Hypothesis 4. This result continues to hold if we restrict attention to accepted proposals involving strictly positive quantities.[28] Thus, counter to Hypothesis 2, quantities traded are not higher in FR-DFL and FR-IOM relative to the Constant M case. Further, quantities traded are highest in the k-PCT treatment.

Regarding Hypothesis 3, a Wald test on the null of no difference in the coefficient estimates for FR-DFL and FR-IOM cannot be rejected ($p > .10$), regardless of whether we restrict the sample to strictly positive traded quantities or not. Figure 1 confirms the latter finding, as the confidence intervals for the FR-DFL and FR-IOM treatments overlap.

[27] The means in Figures 1-2 are slightly different than those reported in Table 5 because in the figures, the DM means are calculated across all periods of all sequences of all sessions while in Table 5 means are first averaged by period and then by first half, second half, or all periods of a sequence.

[28] Some proposals involving $q = 0$ units of the DM good are accepted by producers (they may or may not involve positive token amounts). Such 0-quantity proposals are excluded from the price analysis (3rd column) since the DM prices is calculated as d/q.

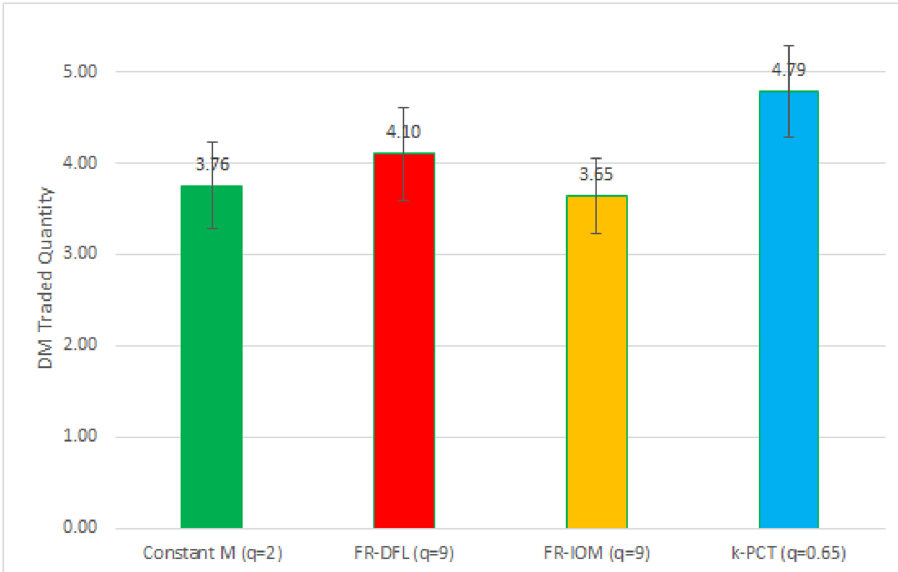

Figure 1: Mean DM Traded Quantity Across Treatments with 95% Confidence Intervals. Monetary equilibrium predictions in parentheses.

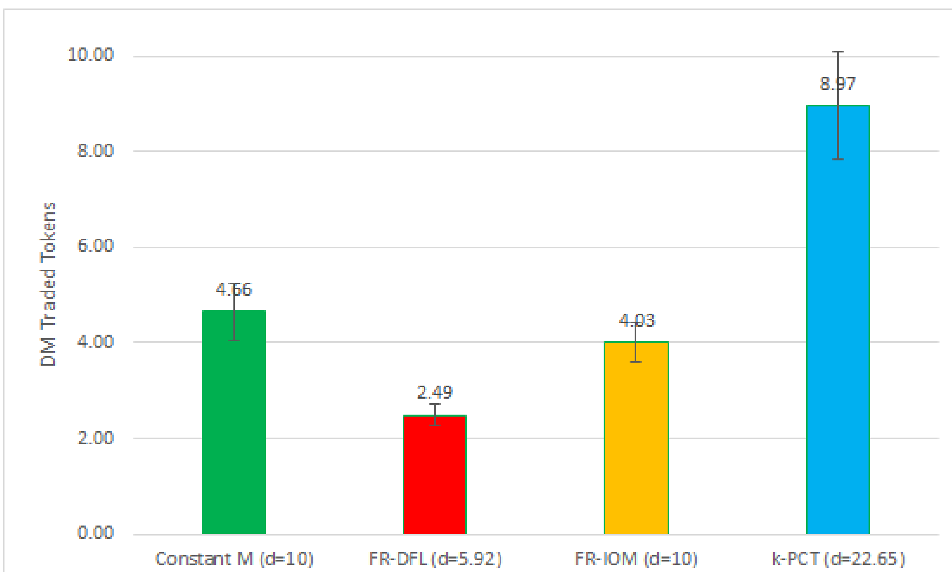

Figure 2: Mean DM Traded Tokens Across Treatments with 95% Confidence Intervals. Monetary equilibrium predictions in parentheses.

5.3 Welfare Comparisons

We next turn to a comparison of welfare differences across our four treatments. Since utility is linear in the CM, and that market should only be used to rebalance money holdings (i.e., in the CM there are no aggregate payoff consequences) one measure of period welfare –overall welfare– amounts to computing the sum of the surpluses across pairs in the DM round of each period. We

Table 6: Regression Analysis of Traded Quantities on Treatment Dummies

	(1) DM Traded Q†	(2) DM Traded Q
Constant	3.756***	4.224***
	(0.239)	(0.249)
FR-DFL	0.346	0.557
	(0.349)	(0.371)
FR-IOM	-0.109	0.011
	(0.315)	(0.324)
k-PCT	1.030***	0.682*
	(0.344)	(0.352)
Observations	1943	1737
R^2	0.011	0.005

Standard errors in parentheses are clustered at the subject level.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

† Includes accepted trades of 0 quantities.

normalize this measure by the first best welfare, equal to $u(q^*) - q^*$ times the number of pairs (7). However as noted in Table 3, only between 40 and 50 percent of proposals are accepted on average. The theory predicts 100 percent acceptance rate regardless of the monetary regime. That is, in theory, monetary policies should not affect the extensive margin, i.e., whether trade occurs or not. Instead, monetary policy impacts only the intensive margin, i.e., the quantity of the DM good traded. Since in the data we do not find that all proposals are accepted, to better understand the welfare consequences of various monetary policies, we construct a second measure of welfare –intensive margin welfare– that computes the sum of the DM surpluses achieved in every period, normalized by $u(q^*)-q^*$ times the number of pairs *who agreed to trade.* This second welfare measure better captures the intensive margin effects of monetary policies.

To make better sense of both welfare measures, we report the ratio of each welfare measure to the first best level over all periods and over the first and second half of each sequence, by treatment, in Table 7. Regarding the intensive margin welfare measure, we find that welfare is highest in the k-PCT treatment and lowest in the FR-DFL treatment. Regarding the overall measure, differences in welfare across treatments are less pronounced, but this may reflect the different acceptance rates across treatments. For example, in the k-PCT treatment, pairs trade higher amounts on the intensive margin, (see Table 6) but higher rejection rates in this treatment (as confirmed by Table 4 above) reduce the overall welfare measure in this treatment.

Statistical evidence for treatment differences in these two welfare measures across treatments is provided in Figure 3 and Table 8. Figure 3 shows mean intensive margin welfare across the four treatments along with 95 percent confidence intervals. As the figure reveals, intensive margin welfare is not significantly different across the treatments Constant M, FR-DFL and FR-IOM. However, the intensive margin welfare ratio is significantly higher in the k-PCT treatment relative to the other three treatments. Considering overall welfare, Figure 3 reveals no significant differences

Table 7: Welfare Relative to the First Best: First Half, Second Half and All Periods of Each Sequence, by Treatment

	Intensive Margin Welfare Relative to First Best			Overall Welfare Relative to First Best		
Treatment	First Half	Second Half	All	First Half	Second Half	All
Constant M	0.68	0.55	0.61	0.31	0.24	0.27
Monetary Equ.	0.62	0.62	0.62	0.62	0.62	0.62
FR-DFL	0.72	0.45	0.59	0.35	0.20	0.27
Monetary Equ.	1	1	1	1	1	1
FR-IOM	0.69	0.54	0.61	0.36	0.25	0.30
Monetary Equ.	1	1	1	1	1	1
k-PCT	0.73	0.68	0.70	0.33	0.26	0.30
Monetary Equ.	0.33	0.33	0.33	0.33	0.33	0.33

in these ratios across all four treatments.

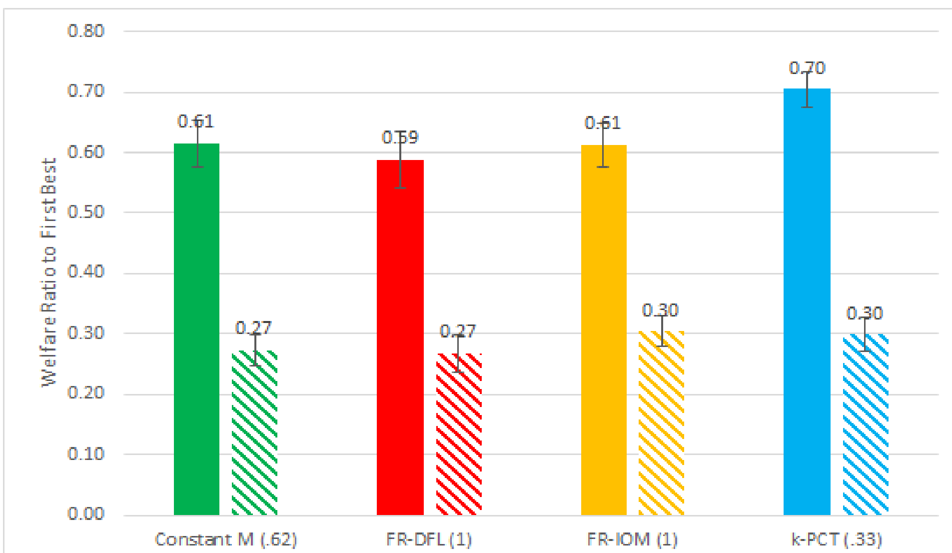

Figure 3: Mean Intensive Margin (left solid bar) and Overall (right striped bar) Welfare Ratio to First Best and 95% Confidence Interval. Monetary equilibrium predictions in parentheses.

In Table 8, the dependent variables are intensive margin welfare for each period or overall welfare for each period. The first regression involving the intensive margin welfare measure again shows that welfare is significantly higher in the k-PCT treatment relative to the baseline Constant M treatment. The same is true for comparisons between k-PCT and either FR-DFL and FR-IOM according to Wald tests ($p < .01$ for both tests). There are no other pairwise treatment differences. The finding that intensive margin welfare is highest in the k-PCT treatment is at odds with the theory. We discuss why this might be the case later in section 5.6.

The second regression using the overall welfare measure shows that welfare is marginally higher

Table 8: Regression Analysis of Welfare on Treatment Dummies

	(1) Intensive Margin Welfare Relative to First Best	(2) Overall Welfare Relative to First Best
Constant	0.615***	0.273***
	(0.020)	(0.013)
FR-DFL	-0.026	-0.004
	(0.031)	(0.020)
FR-IOM	-0.003	0.031*
	(0.027)	(0.018)
k-PCT	0.090***	0.026
	(0.025)	(0.019)
Observations	614	624
R^2	0.032	0.008

Robust standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

in the FR-IOM treatment compared with the Constant M treatment. Overall welfare in the FR-IOM treatment is also marginally greater than in the FR-DFL treatment according to a Wald test ($p = .0815$). There are no other pairwise treatment differences using the overall welfare measure.

The difference between the welfare results using the intensive margin versus the overall welfare measure can be attributed to the differences in proposal acceptance rates. As Table 3 reveals, acceptances were highest in FR-IOM and lowest in k-PCT. As we have noted, monetary policies are not predicted to impact on acceptance rates; in equilibrium acceptance rates are supposed to be 100 percent. Since they are not, the intensive margin welfare is, in our view, a more accurate measure of the impact of monetary policy.

5.4 Price Levels

We now consider the effect of our different monetary regime treatments on DM and CM price levels. In the next section we will consider rates of change in these prices over time. Figures 4 and 5 show mean DM and CM prices across the four treatments along with 95 percent confidence interval bars. The first bar in these figures shows the mean DM or CM prices in the first period of each new sequence while the second bar shows mean DM and CM prices over all periods.[29]

Recall from Table 1 that the mean first period DM price across treatments is, from lowest to highest, 1.11 for the two FR treatments, 5 for the Constant Money treatment and 15.38 for the k-PCT treatment. As Figure 4 reveals, the first period prices generally differ from these level

[29]Table C7 in Appendix C reports on mean DM and CM prices over the first half, second half and all periods of each sequence by session and treatment. Figures C1-C4 plot mean traded DM and CM prices over time against equilibrium predictions.

predictions (except for the FR-IOM treatment), but there is support for the predictions qualitatively as the lowest prices are observed in the two FR treatments and the highest are observed in the k-PCT treatment. The mean first period CM price predictions are the same except for the FR-IOM treatment, where the CM price is 1.33, reflecting the temporary 20 percent increase in the money supply from interest payments. Again, we see in Figure 5 qualitative support for the predictions, though again the data are generally different from the precise level predictions.[30]

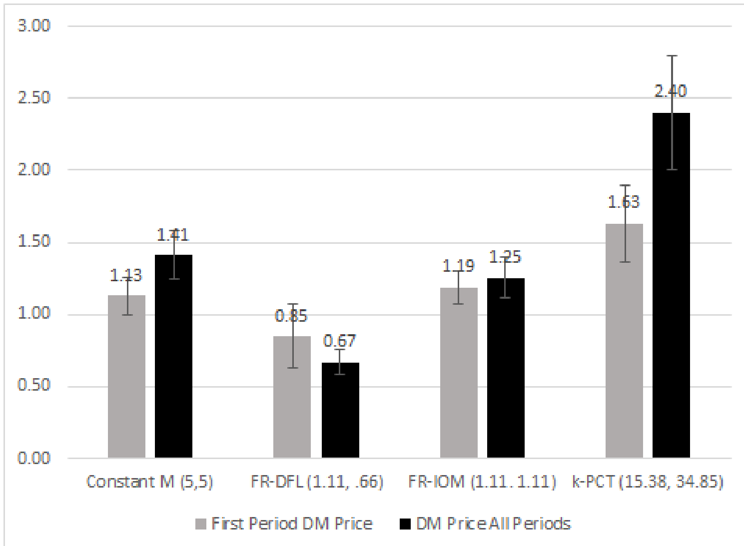

Figure 4: Mean DM Prices Across Treatments, First Period of a Sequence and All Periods along with 95% Confidence Intervals. Monetary equilibrium predictions in parentheses (First Period, Mean of All Periods).

Consistent with qualitative predictions of the theory (see Table 1) and Hypothesis 5, prices in both the DM and CM are *lower* in the FR-DFL and FR-IOM treatments relative to the Constant M baseline treatment, while prices in the k-PCT treatment are *higher* relative to the Constant M baseline treatment (see also the regression results presented in Table C8 in Appendix C for further evidence). The evidence presented in this section suggests that monetary policy was impacting prices in both the DM and CM in ways that are predicted by the theory.

5.5 Prices Over Time

We next address Hypothesis 6, which concerns changes in prices over time in the DM and CM. We first compare the FR-DFL and k-PCT treatments where we expect deflation and inflation of the price levels, respectively. Recall that in the FR-DFL, the deflation rate of both the DM and CM price should be 16.67 percent over time, while in the k-PCT treatment, the inflation rate of both the DM and CM price should be 16.67 percent over time. Table 9 regresses the log of the average DM and the log of CM prices each period on the period number within each sequence and four session dummies. In the DM, prices are marginally lower over time in the FR-DFL treatment and

[30]Theory predicts that prices change over time in the FR-DFL and k-PCT treatments. We used realized sequence lengths to compute predicted price paths. Then we computed price means using the same procedure we used to compute means in the data.

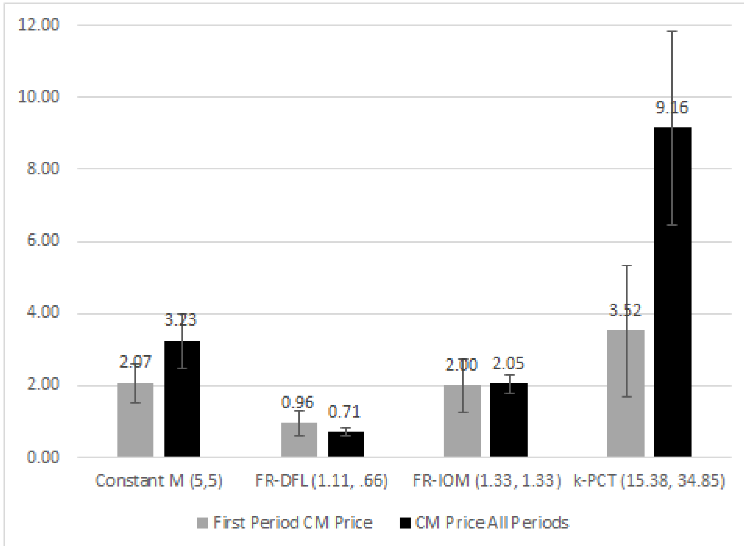

Figure 5: Mean CM Prices Across Treatments, First Period of a Sequence and All Periods along with 95% Confidence Intervals. Monetary equilibrium predictions in parentheses (First Period, Mean of All Periods).

not changing much in the k-PCT treatment. By contrast, in the CM, prices in the FR-DFL are significantly decreasing over time at an estimated rate of -14.1% per period, while in the k-PCT treatment they are significantly increasing over time at an estimated rate of 20% per period. We further tested whether the estimated rate of decrease in the CM of the FR-DFL treatment was significantly different from the prediction of -16.67% and we found, remarkably, that we could not reject the null of no difference ($p = .184$). Similarly, we tested whether the estimated rate of increase in the CM of the k-PCT treatment was significantly different from the prediction of 16.67%, and we found that the null could be rejected ($p = .052$) in favor of the alternative that prices were increasing slightly faster.

In Table 10 we examine DM and CM prices over time in the Constant M and FR-IOM treatments, as in these two treatments, we expect prices to be constant over time. We again regress the log of the average DM price and the log of the CM price on the period number within a sequence and dummies for four of the five sessions. The regressions reveal that, with one exception DM and CM prices are constant over time. The exception is for DM prices in the constant M treatment where we observe a small increase in prices over time.

We further consider support for the quantity theory of money in our experimental data. According to the quantity theory, in the steady state, the rate of change of prices equals the rate of change in the money supply. We look for evidence of this quantity theory prediction in our price data both in the DM and the CM. Some evidence in support of the quantity theory prediction is reported in Table 9 where we found that CM prices in the FR-DFL treatment declined at a rate of 14.1 percent and CM prices in the k-PCT treatment increased at a rate of 20 percent, which are close to the predicted 16.67 percent decline or increase, respectively. However, DM prices did not appear to respond appropriately to changes in the money supply. A more direct test of the quantity theory prediction is presented in Table 11 where we regress the log of the average DM price and the log of the CM price on the log of the money supply. The coefficient estimate on log

Table 9: DM and CM Prices Over Time: FR-DFL versus k-PCT

	FR-DFL DM	FR-DFL CM	k-PCT DM	k-PCT CM
Period within a Sequence	-0.029*	-0.141***	0.002	0.200***
	(0.015)	(0.019)	(0.022)	(0.017)
Session=1	-0.241*	-0.655***	-0.514***	-0.024
	(0.123)	(0.178)	(0.144)	(0.204)
Session=2	-0.484***	0.646***	-0.322***	-0.682***
	(0.080)	(0.134)	(0.105)	(0.136)
Session=3	-0.333***	-0.497***	-0.181	-0.888***
	(0.083)	(0.118)	(0.123)	(0.150)
Session=4	-0.690***	-0.266***	-0.250***	0.372*
	(0.087)	(0.098)	(0.078)	(0.197)
Constant	0.016	0.126	0.255**	0.754***
	(0.073)	(0.104)	(0.108)	(0.135)
Observations	138	155	83	156
R^2	0.272	0.579	0.132	0.552

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 10: DM and CM Prices Over Time: Constant M versus FR-IOM

	Constant M DM	Constant M CM	FR-IOM DM	FR-IOM CM
Period within a Sequence	0.043***	0.028	0.006	-0.020
	(0.012)	(0.020)	(0.013)	(0.018)
Session=1	0.463***	0.891***	-0.375***	-0.598***
	(0.135)	(0.221)	(0.128)	(0.172)
Session=2	0.041	0.155	-1.003***	-0.115
	(0.104)	(0.182)	(0.256)	(0.161)
Session=3	0.171	0.335*	-0.548***	-0.426**
	(0.104)	(0.170)	(0.146)	(0.168)
Session=4	-0.057	-0.184	-0.464**	0.610***
	(0.076)	(0.121)	(0.193)	(0.161)
Constant	-0.001	0.318**	0.239***	0.632***
	(0.080)	(0.127)	(0.076)	(0.133)
Observations	146	156	61	156
R^2	0.268	0.226	0.316	0.310

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

(Money Supply) represents the ratio of the rate of change of prices to the rate of change of the money supply. According to the quantity theory of money, this ratio should equal 1 in both the DM and CM rounds of the FR-DFL and k-PCT treatments.

Table 11: DM and CM Prices Relative to the Money Supply, FR-DFL versus k-PCT

	FR-DFL DM	FR-DFL CM	k-PCT DM	k-PCT CM
log(Money Supply)	0.559***	0.773***	0.631***	1.294***
	(0.101)	(0.107)	(0.065)	(0.109)
Session=1	-0.302*	-0.655***	-0.205*	-0.024
	(0.155)	(0.178)	(0.109)	(0.204)
Session=2	-0.254**	0.646***	-0.369***	-0.682***
	(0.102)	(0.134)	(0.098)	(0.136)
Session=3	-0.198	-0.498***	-0.189*	-0.888***
	(0.121)	(0.118)	(0.097)	(0.150)
Session=4	-0.628***	-0.266***	0.411***	0.372*
	(0.121)	(0.098)	(0.144)	(0.197)
Constant	-2.841***	-3.832***	-2.678***	-5.443***
	(0.451)	(0.470)	(0.366)	(0.611)
Observations	138	155	152	156
R^2	0.330	0.579	0.463	0.552

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

As Table 11 reveals, the coefficient estimates are significantly positive in all cases indicating that prices track changes in the money supply, decreasing in the FR-DFL treatment and increasing in the k-PCT treatment. Consistent with the analysis reported in Table 9, coefficient estimates on the log (Money Supply) are closer to 1 in the CM than in the DM of these two treatments. Further, we again find that prices significantly under-react to changes in the money supply in the DM and CM of the FR-DFL treatment and in the DM of the k-PCT treatment, and significantly over-react in the CM of the k-PCT treatment.

5.6 Discussion

The finding that intensive margin welfare is highest under the k-PCT rule is puzzling. We consider two possible explanations: 1) Liquidity constraints and 2) Precautionary motives.

We first consider the possibility that liquidity constraints played a role. We note that in all sessions, subjects faced uncertainty about the price levels that would prevail in both the DM and CM rounds. They only learned about prices in the DM if a trade occurred and in the CM, they only learned about prices after the market had cleared. Even though Table C9 in Appendix C provides evidence that subjects were using the CM to rebalance, this uncertainty with respect to token prices may have affected subjects' ability to properly re-balance their money holdings in the CM. In addition, in both the FR-DFL and FR-IOM treatments subjects paid a lump-sum token tax at the end of the CM round, which further reduced their token holdings. If they did not have sufficient tokens to pay the tax, they had to produce enough units of the CM good X at the market price P to generate the additional tokens needed, which occurred 18.8% of the time in the FR-DFL treatment and 13% of the time in the FR-IOM treatment.[31] As a result, more subjects in the two FR treatments entered the next DM round with zero or low token balances, which limited their ability to trade. By contrast, in the k-PCT treatment, consumers can never enter the DM with 0 tokens since there is a lump-sum transfer of tokens to all players at the end of each CM round.

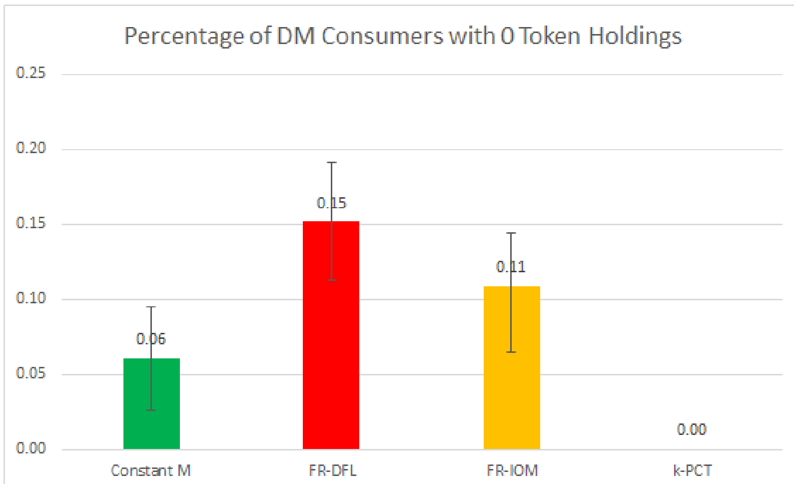

Figure 6: Percentage of DM Consumers with 0 Tokens by Treatment with 95% Confidence Intervals

Figure 6 provides support for this conjecture. We observe that 15 percent of consumers in the FR-DFL and 11 percent of consumers in the FR-IOM treatments enter DM rounds with 0 tokens. There is a somewhat lower proportion of consumers with 0 tokens in the Constant M treatment. Most importantly and by design, subjects in the k-PCT treatment always have tokens available at the start of any DM round. The inflation of the k-PCT treatment alleviates liquidity constraints on those who do not properly re-balance in the CM, and this feature of the k-PCT treatment may account for the higher welfare that we observe in that treatment relative to the other three treatments where the money stock remains constant or decreases over time.

We next consider the possibility that precautionary motives are more prominent in FR treatments with lump-sum taxation. By precautionary motives, we mean subjects' tendency to hold on to money in uncertain situations. Precautionary motives imply that consumers in the k-PCT treatment may have been more generous in their token offers over time as there was a growing supply of tokens to offer.[32] Conversely, consumers may have been more reluctant to spend in the DM of the FR-DFL and FR-IOM treatments, since they needed to pay lump-sum taxes in the next CM, and they faced some uncertainty as to whether could successfully rebalance in the CM. To address this conjecture, we again consider accepted DM offers, but we focus on how generous those token offers were relative to the consumer's available token balances. We regressed the ratio of the consumer's token offer, d, to their available token holdings, m_c in all DM rounds on three treatment dummy variables, and we controlled for the DM quantity that the consumers received in exchange for their

[31] Often, it was the same few subjects who owed taxes.

[32] Another way of characterizing the same phenomenon is the "hot potato effect" wherein agents seek to get rid of money faster in rapidly inflating economies.

token offer (Traded q). Recall that the theoretical prediction is for consumers to offer *all* of their available tokens in every DM round, that is, the monetary policy regime (treatment) should not matter. As Table 12 reveals, we find that consumers are significantly more generous with money offers as a percentage of their money holdings in the k-PCT treatment (where they have the most tokens, on average) and significantly less generous in the FR-DFL and FR-IOM treatments (where they have the least tokens on average) relative to the Constant Money control treatment. This evidence is consistent with a precautionary motive for holding money. Specifically, subjects needed money to pay taxes in the FR-DFL and FR-IOM treatments, where they potentially faced some uncertainty as to whether they would succeed in rebalancing their money holdings in the CM for the dual purpose of paying taxes at the end of the CM and trading in the next DM. On the other hand, subjects did not need to pay taxes following the CM market of the k-PCT treatment. Furthermore, subjects also received a lump-sum transfer at the end of the CM, so they were sure they would have tokens at the beginning of the subsequent DM. These factors may have also facilitated more generous offers in the k-PCT treatment relative to other treatments.

Table 12: Regression of Consumer's d/m_c on treatment dummies and controlling for the quantity traded

	d/m_c
Constant	0.449***
	(0.031)
FR-DFL	-0.085**
	(0.034)
FR-IOM	-0.083**
	(0.036)
k-PCT	0.071*
	(0.038)
Traded q	0.017***
	(0.002)
Observations	1817
R^2	0.121

Standard errors clustered at the subject level in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6 Conclusions

The Friedman rule is the "most celebrated proposition in...'pure' monetary theory." (Woodford 1990, p. 1068). The rule is that monetary policy should be conducted so as to implement a zero nominal interest rate, which can be achieved by decreasing the supply of money at the real rate of interest on alternative safe assets or by paying that same rate of interest on money holdings. To our knowledge the Friedman rule has not been implemented in practice, perhaps because of various implementation challenges, e.g., limited price flexibility, lump-sum taxation, or the administration costs of paying interest on money. However, these challenges can be overcome in the laboratory where we can implement the "simple hypothetical society" that Friedman (1969) imagined in formulating the monetary policy rule that was optimal for that environment. While the Friedman rule is the optimal monetary policy in a wide variety of monetary models, we choose to implement it in the Lagos and Wright (2005) model, a tractable, micro-founded environment that makes explicit the frictions giving rise to the use of money.

We find that the Friedman rule, while theoretically optimal, is no better than a constant money supply rule in terms of welfare. Further, the manner in which the Friedman rule is implemented, by decreasing the money supply at a constant rate over time or by paying interest on money holdings does not matter much for this result. Contrary to the theoretical predictions, quantities traded and intensive margin welfare are highest in the k-PCT treatment. In practice, current monetary policy in most developed countries aims for an inflation target of 2 percent, which bears closest resemblance to our k-PCT treatment. Indeed, one can perhaps view the main message of our paper as rationalizing the actual practice of moderate inflationary monetary policy and avoidance of the Friedman rule by central bankers, despite the fact that the Friedman rule represents the optimal policy in the economy that we study.

We attribute our findings to a combination of liquidity constraints and precautionary motives. In future research, it would be of interest to explore modifications to our model that could further our understanding of the departures from theoretical predictions. For instance, Jiang et al. (2019) consider the k-PCT rule and other inflationary policies with centralized markets and fixed roles in both markets. Another possibility would be to automate the centralized market to facilitate the necessary re-balancing of money holdings. Future research could add credit markets, multiple currencies and assets to the model and explore the impact of more explicit monetary policies, involving, e.g., open market operations. We think that laboratory experiments are a natural complement to theoretical and empirical analyses of the impact of monetary policy using non-experimental field data. Our paper provides evidence that such experiments are both possible and informative.

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Appendices for Online Publication Only

Appendix A: Theoretical Framework

In this section we provide more details on the theoretical framework that guided our experimental implementation, and the steps we followed to obtain the monetary equilibrium.

We denote by $V_t(m_t^i)$ and $W_t(m_t^i)$ the decentralized and centralized market value functions for agent i with m_t^i money holdings at the beginning of the decentralized market or centralized market, in period t, respectively.Let A denote the set of agents and $\varphi : A \twoheadrightarrow A$ be an exhaustive bilateral matching rule, so that no agent remains unmatched. In a bilateral match where the consumer has m money holdings and the producer has $\widetilde{m}$ money holdings, $q_t(m, \widetilde{m})$ and $d_t(m, \widetilde{m})$ denote the terms of trade, i.e., the amount of the DM good produced and the amount of money the consumer pays, respectively. We denote by X_t, Y_t and m_{t+1}^i consumption of the general good, production of the general good and next period's money holdings, respectively.
Then, the decentralized market value function, $V_t(m_t^i)$, can be written as:

$$\begin{aligned} V_t(m_t^i) &= \Bigg\{ \frac{1}{2}\sum_{j\neq i} \Big[u(q_t(m_t^i, m_t^j)) + W_t(m_t^i - d_t(m_t^i, m_t^j)) \Big] \Pr\left(\varphi(i) = j\right) \\ &+ \frac{1}{2}\sum_{j\neq i} \Big[-c(q_t(m_t^j, m_t^i)) + W_t(m_t^i + d_t(m_t^j, m_t^i)) \Big] \Pr\left(\varphi(i) = j\right) \Bigg\}. \end{aligned}$$

The value function at the beginning of the CM, $W_t(m_t^i)$, satisfies:

$$W_t(m_t^i) = \max_{X_t, Y_t, m_{t+1}^i} \left\{ X_t - Y_t + \beta V_{t+1}(m_{t+1}^i) \right\} \tag{A.1}$$

$$\text{s.t. } X_t = Y_t + \phi_t((1+i_m)m_t^i - m_{t+1}^i) + \tau_t \tag{A.2}$$

where τ_t is the real value of the lump-sum transfer or tax from the government, and i_m denotes the interest on money. The budget constraint in the CM implies that consumption of the CM good should be equal to production plus the real value of money that an agent holds at the beginning of the CM after the interest payment, minus the real value of money, $\phi_t m_{t+1}^i$, the agent chooses to bring to the next DM. By substituting $X_t - Y_t$ from the budget constraint into $W_t(m_t^i)$, the value function at the beginning of the CM can be simplified to:

$$W_t(m_t^i) = \phi_t(1+i_m)m_t^i + \tau_t + \max_{m_{t+1}^i} \left\{ -\phi m_{t+1}^i + \beta V_{t+1}(m_{t+1}^i) \right\}. \tag{A.3}$$

That is, the lifetime expected utility of an agent in the CM is given by the sum of his real balances, the lump-sum transfer and the continuation value at the beginning of the next DM minus the cost of the investment in real balances. Importantly, quasilinearity implies that the CM value function is linear in real balances, which simplifies the determination of terms of trade in the DM, discussed next.

The DM value function can be further simplified by solving for the terms of trade in the DM, q_t and d_t, which we assume are determined via a take-it-or-leave-it trading protocol.[33] Given the

[33]The take-it-or-leave-it trading protocol delivers the most efficient allocation in the class of generalized Nash bargaining trading protocols.

assumptions of quasi-linearity, the terms of trade (q_t,d_t) in a pair where the buyer holds money holdings m_t are determined by the solution to

$$\begin{aligned} \max_{q_t,d_t} \quad &= \quad [u(q_t) - \phi_t(1+i_m)d_t] \\ \text{s.t.} \quad & -c(q_t) + \phi_t(1+i_m)d_t \geq 0 \\ & q_t \geq 0, \quad 0 \leq d_t \leq m_t. \end{aligned}$$

If the constraint $d_t \leq m_t$ does not bind, then the solution to this optimization problem is $q_t = q^*$ and $d_t = m_t^* = \frac{c(q^*)}{\phi_t(1+i_m)}$. If $m_t \leq m_t^*$, then the constraint $d_t \leq m_t$ binds. This implies $d_t = m_t$, and q_t solves $c(q_t) = \phi_t(1+i_m)m_t$. Note that since the terms of trade only depend on the buyer's money holdings and using the linearity properties of the CM value function, we can further simplify the value function $V_t(m_t)$.

Specifically, following the same steps as in Lagos and Wright (2005) or Rocheteau and Nosal (2017), the amount of money carried over from the centralized to the decentralized market (or savings), m_{t+1}^i, solves a sequence of simple optimization problems:

$$\max_{m_{t+1}^i} \left\{ -(\phi_t - \beta(1+i_m)\phi_{t+1})m_{t+1}^i + \beta\frac{1}{2}\left[u(q_{t+1}(m_{t+1}^i) - (1+i_m)\phi_{t+1}d_{t+1}(m_{t+1}^i)\right] \right\}.$$

That is, the choice of how much money to bring to the next DM, is governed by trading off the benefit (the liquidity return to money) given by $\beta\frac{1}{2}\left[u(q_{t+1}(m_{t+1}^i) - (1+i_m)\phi_{t+1}d_{t+1}(m_{t+1}^i)\right]$ with the opportunity cost of holding money $-(\phi_t - \beta(1+i_m)\phi_{t+1})m_{t+1}^i$ associated with delayed consumption. Any equilibrium must satisfy $\phi_t \geq \beta(1+i_m)\phi_{t+1}$ or $\mu \geq \beta(1+i_m)$. Thus note that the minimum inflation rate consistent with an equilibrium is $\frac{\phi_t}{\phi_{t+1}} = \mu = \beta(1+i_m)$, i.e., the Friedman rule. Also, note that under the Friedman rule, the opportunity cost of holding money is zero.

The optimization problem described above delivers the following equation for the steady state monetary equilibrium solution, which appears as equation (1) in Section 3:

$$\frac{u'(\widetilde{q})}{c'(\widetilde{q})} = 1 + \frac{\mu - \beta(1+i_m)}{\frac{\beta}{2}(1+i_m)}. \tag{A.4}$$

Note that $\widetilde{q} \leq q^*$ since the function u'/c' is decreasing and $\mu \geq \beta(1+i_m)$, and that $\widetilde{q} \to q^*$ as $\mu \to \beta(1+i_m)$.

Appendix B: Experimental Instructions

Here we provide the experimental instructions from the FR-DFL treatment. Other instructions are similar. Copies of the instructions used in all four treatments can be found at: `https://www.socsci.uci.edu/~duffy/MonetaryPolicy/`.

Instructions

Welcome to this experiment in the economics of decision making. Funding for this experiment has been provided by the National Science Foundation. During today's session, you will be called upon to make a series of decisions. If you follow the 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. Kindly silence all mobile devices.*

Overview

There are 14 participants in today's session. Each participant will make consuming, producing, buying and 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 is 1,2,3,4 or 5, the sequence will continue with another two-round period. If the random number is a 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 the experiment. Each point you earn is worth $0.40.

At the beginning of each new sequence, each of the 14 participants is endowed with 10 "tokens". Thus the total number of tokens is $14 \times 10 = 140$ at the start of each new sequence but this number will gradually decrease over the course of a sequence as explained below. Participants may choose whether or not to use tokens for exchange purposes as also discussed below. Tokens have no value in terms of points but they may help you to earn points. You will also need tokens to pay a token tax as explained below.

Timing and Pairing

Recall that each period consists of two rounds. In the first round of each period, the 14 participants will be randomly matched in 7 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 these 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 another participant. All pairings are equally likely. In each pair, one participant is randomly chosen to be the **Consumer** and the other is the **Producer**. 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 can be produced by Producers and traded to Consumers. This good is "perishable" because it cannot be carried over into any other round or period. Consumers receive a benefit in points from consuming some quantity of the perishable good which is added to their point total. Producers incur a cost in points for producing some quantity of the perishable good which is subtracted from their point total. Table 1 shows the benefits to Consumers and the costs to Producers in points from various quantities consumed and produced as well as the point difference. For example, if you are a Consumer and you succeed in consuming 5 units of the good, you get a benefit of 7.35 points while the Producer who agreed to produce those 5 units for you incurs a cost of 5 points. Thus, the net gain is 2.35 points.

Quantity	Consumer's Benefit in Points	Producer's Cost in Points	Benefit-Cost (net gain) in Points
0	0	0	0
1	2.11	1	1.11
2	3.61	2	1.61
3	4.94	3	1.94
4	6.18	4	2.18
5	7.35	5	2.35
6	8.46	6	2.46
7	9.54	7	2.54
8	10.58	8	2.58
9	11.59	9	2.59
10	12.58	10	2.58
11	13.55	11	2.55
12	14.49	12	2.49
13	15.42	13	2.42
14	16.34	14	2.34
15	17.24	15	2.24
16	18.12	16	2.12
17	18.99	17	1.99
18	19.86	18	1.86
19	20.71	19	1.71
20	21.55	20	1.55
21	22.38	21	1.38
22	23.20	22	1.20
23	24.02	23	1.02
24	24.83	24	0.83
25	25.62	25	0.62
26	26.42	26	0.42
27	27.20	27	0.20

Table 1: Benefits and Costs (in Points) for Consumers and Producers, Decentralized Meeting

Consumers move first. They are first informed of their own token holdings as well as the token holdings of their matched Producer. Consumers must then decide 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 that Producer for this amount of goods –see Figure 1. Consumers can request any amount of the good between 0 and 27 units inclusive (fractions allowed) and they can offer to give the Producer between 0 and the maximum number of tokens they currently have available, inclusive (fractions allowed). After all Consumers have made their decisions, it is the Producers turn to make a decision. Producers are informed of their own token holdings as well as the token holdings of their matched Consumer and are presented with their matched Consumer's proposal (amount of good requested and tokens offered in exchange). Producers must decide whether to

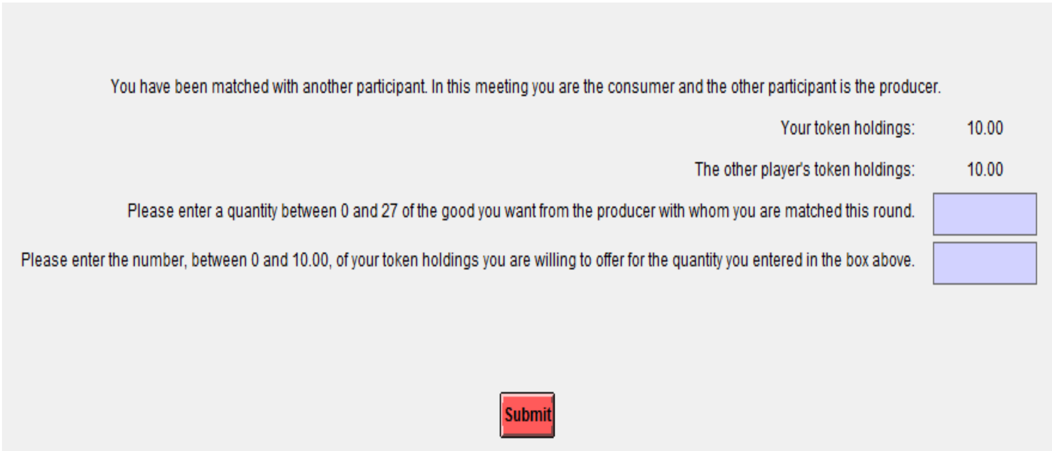

Figure 1: Consumer Decision Screen, Decentralized Market

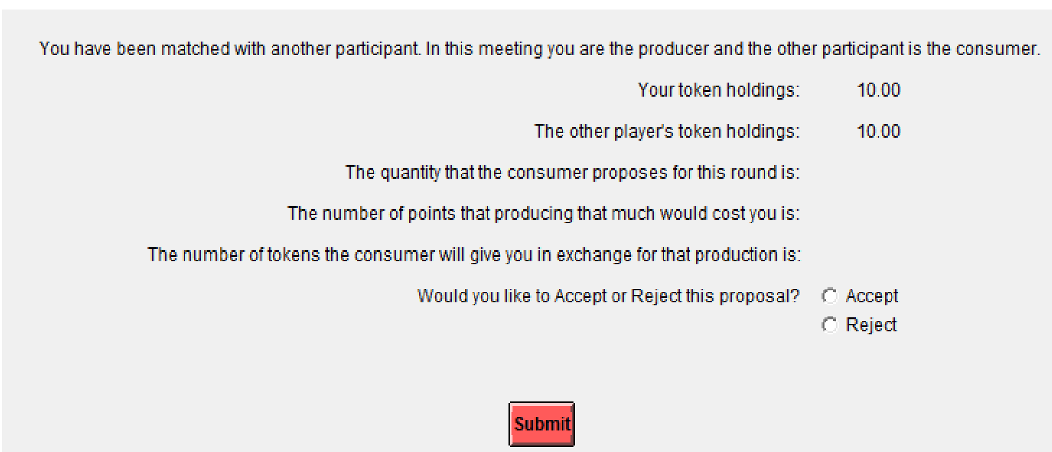

Figure 2: Producer Decision Screen, Decentralized Market

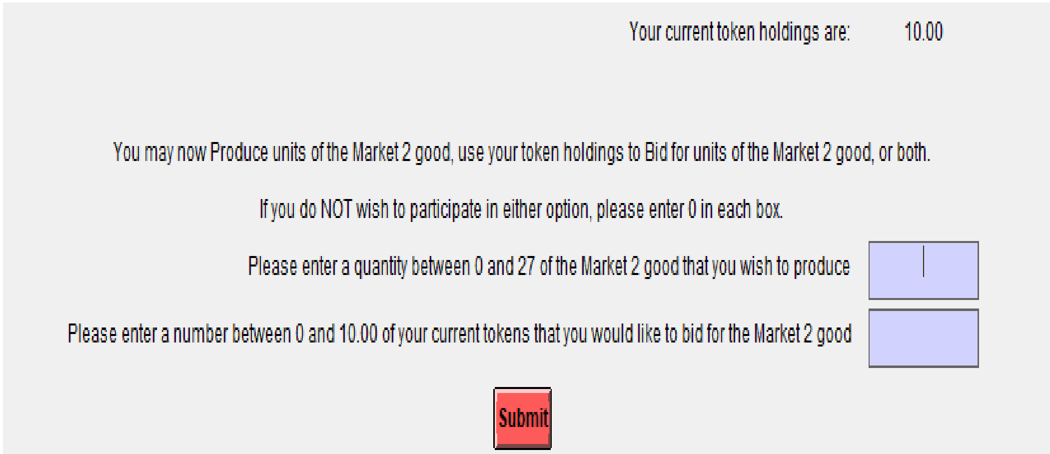

Figure 3: Decision Screen, Centralized Meeting

"Accept" or "Reject" the Consumer's proposal –see Figure 2. If a Producer clicks the Accept button, the proposed exchange takes place: the Producer produces the requested amount of the good, incurs a cost in points from doing so but receives the amount of tokens, if any, the Consumer offered in exchange. The Consumer receives a benefit in points from consumption of the amount of the good produced 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. Note that without agreement by Producers to produce, there can be no exchange and without exchange there is no net gain in points. Recall from Table 1 that, for any positive quantity of the good exchanged, the Consumer's benefit in points always exceeds the Producer's cost in points. Recall also that, on average you will be a Consumer in half of all decentralized meeting rounds and a Producer in the other half.

After all decisions have been made, the results of the Decentralized Meeting (round 1) are revealed. Any exchanges are implemented and you 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). Each participant brings with him/her the token holdings that s/he held 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 can decide whether to: 1) produce-and-sell units of a perishable good called "good X" in exchange for tokens, 2) use tokens to bid for (buy-and-consume) units of good X, 3) do both, or 4) do neither. The decision screen you face in the Centralized Meeting is shown in Figure 3.

Table 2 shows the points 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 3 units of good X and you are able to sell those units (more on this below), then producing those 3 units will cost you 3 points. If you are able to buy and consume 11 units of good X (again, see below), this will give you a benefit of 11 points.

If you want to *produce and sell units* of good X, then enter the quantity you will produce in the first input box of the decision screen (Figure 3). Call this quantity "q". You can produce and

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
23	23	23
24	24	24
25	25	25
26	26	26
27	27	27

Table 2: Benefit and Cost (in Points) for Consumers and Producers, Centralized Meeting

sell any quantity, q, of good X from 0 to 27 units inclusive (fractions allowed). If you do not want to produce and sell any units of good X then enter 0 in the first input box. If you want to use some of your current token holdings to *buy and consume* units of good X, then enter the number of your tokens you wish to bid in the second input box on this same screen. Call the amount of your tokens bid, "b ". You can bid any quantity of tokens up to the maximum number of tokens you currently have available at the start of the Centralized Meeting as shown on your decision screen. If you don't want to bid any of your tokens for units of good X then enter 0 in the second input box. When you are done making these choices, click the red submit button.

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; call this: "Total Amount of Good X Produced." The program also calculates the total number of tokens bid toward units of good X by all participants; call this: "Total Amount of Tokens Bid for Good X." Then 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:

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

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 you are 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:

$$\text{Centralized Meeting payoff in points} = -q + b/P. \qquad (1)$$

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 of 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:

$$\text{New Token Balance} = \text{Old Token Balance} + Pq - b. \qquad (2)$$

Notice several things. First, if $-q + b/P$ is negative (equivalently, if $Pq - b$ is positive[34]), so that you are a *net seller* of good X, then you lose points from the Centralized Meeting according to the formula (1). 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 (2). 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 (1). 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 (2). 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.

Token Tax

Following the outcome of the Centralized Meeting, all participants must pay a tax in terms of tokens. The amount of tokens you have to give up at the end of each period is shown in Table 3 in the column labeled Token Tax Per Participant.

This token tax is determined as follows. At the end of each period, 1/6 of all tokens in the 14-participant economy are taxed away (i.e., removed) so that the total amount of tokens in the next period will always be 1/6 fewer than in the prior period. You are responsible only for paying your equal (1/14th) share of this token tax. For example, at the end of the first period there are $14 \times 10 = 140$ Total Tokens in circulation (2nd column of Table 3.) The total token tax (3rd column

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

Period	Total Tokens	Total Tokens Taxed Away	Token Tax Per Participant
1	140.00	23.33	1.67
2	116.67	19.44	1.39
3	97.22	16.20	1.16
4	81.02	13.50	0.96
5	67.52	11.25	0.80
6	56.26	9.38	0.67
7	46.89	7.81	0.56
8	39.07	6.51	0.47
9	32.56	5.43	0.39
10	27.13	4.52	0.32
...*	...	...	...

* Only shown for the first 10 periods of a sequence.

Table 3: Token Tax Calculations Following the Centralized Meeting

of Table 3 is $1/6 \times 140 = 23.33$ tokens. Since there are 14 participants, your own, equal share of the token tax is $1/14 \times 23.33 = 1.67$ tokens which you must pay following the Centralized Meeting. These tokens are *automatically* removed from each participant's token balance by the computer program so that at the start of period 2 (if the sequence continues to period 2), there is a total of just 116.67 tokens in the economy. This same process continues at the end of each period of a sequence; thus the total token supply in the economy is being reduced by 1/6 at the end of each period. The amount of the token tax you must pay each period is shown only for periods 1-10 in Table 3. If a sequence continues for more than 10 periods, the token tax is calculated in the same manner as described above. Notice that the token tax, like the total number of tokens, is decreasing with the period number of the sequence.

If a participant exits the Centralized Meeting and doesn't have enough tokens to pay the token tax for that period, then two things will happen. First, the participant with insufficient tokens to pay the tax will be automatically required (by the computer program) to produce enough units of Good X at the market price, P, determined in the just completed Centralized Meeting to earn enough tokens to pay the token tax due that period.[35] More precisely, such participants will be required to sell enough units (at a cost to him/herself of 1 point per unit) to earn the token shortfall needed to pay the token tax. Second, the additional units of Good X produced by token-poor participants will be sold to other participants who have successfully paid the token tax and have the most remaining tokens available. These token-rich participants will effectively pay the token tax for the token–poor participants, but in exchange, the token–rich participants will get additional points, equal to the additional amount of Good X they receive from the participants forced to produce additional units of Good X in exchange for tokens at the market price P. Of course, participants can avoid having to produce units of Good X to pay for a token tax short-fall by having enough tokens available to pay the token tax at the end of each period–the amount is indicated in Table 3. Participants needing tokens to pay the tax can always choose to produce units of Good X in the Centralized Meeting.

Your new, after-tax token balance 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

[35]If there is no market price, there will be no exchange in the Centralized Meeting, but the token tax will still be collected with P being set equal to the total token holdings by all participants in the current round divided by 126.

drawn. If the sequence does not continue with a new period, i.e., if a 6 is drawn, 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 10 tokens and the token tax schedule begins anew with the tax for period 1.

Information

Following round 1 (Decentralized Meeting) participants are updated on their point totals and token balances as well as those of the participant with whom they are paired. Nobody is ever informed about the identity of the participant with whom they are paired. Following round 2 (Centralized Meeting) participants learn the market price, P, their updated point total, their cumulative point total for the current sequence and their new, after-tax token balance. For your convenience, you will see a history of your decisions and the outcomes of those decisions in all prior rounds at the bottom of the Decentralized Meeting (DM) or the Centralized Meeting (CM) decision screens.

Determination of your Earnings

At the end 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=$0.40.

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. All participants begin each sequence with 10 tokens. Tokens have no value in terms of points but they may help you to earn points.

3. Each period in a sequence consists of two rounds.

Round 1 **Decentralized Meeting:**

i. Participants are randomly matched in pairs. In each pair, one member is randomly chosen to be the *Consumer* and the other is the *Producer*. Both roles are equally likely.

ii. Consumers decide how many units of a perishable good to request from the Producer they are matched with and how many tokens to offer the Producer for those units.

iii. Producers decide whether to accept or reject the Consumer's proposal.

iv. If the proposal is accepted, the Consumer earns a benefit in points based on the amount of the good exchanged as shown in Table 1. The Consumer's token holdings are decreased by the amount of tokens the Consumer offered the Producer. The Producer's point earnings are decreased by the cost of producing the amount of the good exchanged as shown in Table 1. The Producer's token holdings are increased by the amount of tokens the Consumer offered the Producer. If the proposal is rejected, there is no exchange and no change in point earnings or token balances for either participant.

v. Participants are informed about the point earnings and token balances in their pair.

Round 2 **Centralized Meeting:**

i. All participants interact in the Centralized Meeting and decide individually whether to produce-and-sell good X, buy-and-consume good X, do both or do neither.

ii. Participants who decide to produce-and-sell enter a quantity, q, of units they wish to produce for sale. Participants who wish to buy-and-consume enter the number of their currently available tokens they wish to bid, b, toward units of good X.

iii. The market price, P, of good X is determined as the ratio of the total amount of tokens bid for good X to the total amount of good X produced. If there are no tokens bid or no amount of good X produced, then $P = 0$.

iv. If $P > 0$, then each participant earns Centralized Meeting payoff points according to the formula: $-q + b/P$. Each participant's token balances are adjusted according to the formula: New Token Balance = Old Token Balance $+Pq - b$.

v. Participants are informed of the market price, P, and about their own Centralized Meeting point earnings (if any) and new token balances (if a change has occurred).

4. Following the Centralized Meeting, each participant must pay a token tax. A certain amount of tokens is automatically removed from every participant's token balance so that the total amount of tokens is reduced by 1/6 at the end of each period of a sequence. If you do not have enough tokens to pay the tax, you will have to produce enough units of Good X to acquire tokens from other participants at the current period market price, P, in order to pay the tax.

5. After the token tax is collected, the 2-round period is over. A number (integer) from 1-6 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.

6. If a sequence continues, then a new period begins. After-tax token 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 all participants' token balances are set equal to zero. Depending on the time available, a new sequence may begin. Each participant starts each new sequence with 10 tokens.

7. Points accumulate over all sequences. At the end of the session, each participant's cumulative point total will be converted into cash at the rate of 1 point=$0.40. Token balances are carried over from round to round and from period to period, but *not* from sequence to sequence.

Questions?

If you have any questions, please raise your hand and your question will be answered in private.

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, i.e., the Decentralized Meeting round? Circle one: yes / no.

4. Can you choose whether you are a producer/seller or buyer/consumer in the second round of a period, i.e., the Centralized Meeting round? Circle one: yes / no.

5. Does your after-tax token balance carry over from period to period? Circle one: yes / no. From sequence to sequence? Circle one: yes / no.

6. Suppose it is period 3 and you start round 1 (the Decentralized Meeting) holding 8 tokens. Suppose further that you are the Consumer in this meeting. You propose to buy and consume 4 units in exchange for all 8 of your tokens and the Producer accepts your proposal.

   a. What is your payoff in points from the Decentralized Meeting round? (Use Table 1) __________

   b. What is your new token balance at the end of the Decentralized Meeting round? __________

7. Suppose you enter round 2 (the Centralized Meeting) with 0 tokens. Suppose you choose to produce and sell $q = 3$ units of Good X. You cannot bid for (buy and consume) any units of good X as you have 0 tokens available ($b = 0$). After all participants have made their decisions, it turns out that the market price, $P = 2$.

   a. What is your payoff in points from the Centralized Meeting? (Use Formula 1 or Table 2) __________

   b. What is your new token balance? (Use Formula 2) __________

   c. If it is period 3 of a sequence, the token tax you face is 1.16 tokens. What is your after-tax token balance? __________

   d. If the sequence continues with a new period and you are a Consumer in the Decentralized Meeting of that new period, what is the maximum number of tokens you can offer the Producer you are matched with in exchange for the good in the Decentralized Meeting? __________

8. Suppose you enter round 2 (the Centralized Meeting) with 10 tokens. You choose not to produce and sell any units of good X but you choose to buy and consume units of good X by bidding 5 of your tokens and i.e. $q = 0$ and $b = 5$. The market price turns out to be 1.

   a. How many units of good X were you able to *buy and consume*? (Use Table 2) __________
   What is your payoff in points from the Centralized Meeting? (Use Formula 1 or Table 2) __________

   b. What is your new token balance? (Use Formula 2) __________

c. If it is period 2 of a sequence, the token tax you face is 1.39 tokens. What is your after-tax token balance? ____________

d. If the sequence continues with a new period and you are a Consumer in the Decentralized Meeting of that new period, what is the maximum number of tokens you can offer the Producer you are matched with in exchange for the good in the Decentralized Meeting?

____

9. True or False: If you don't have any tokens, you don't have to pay the token tax. Circle one: True False.

10. True or False: Your point total from all sequences will be converted into money and paid to you in cash at the end of the session. Circle one: True False.

Appendix C: Additional Experimental Data and Findings

C.1 Acceptance Rates and Discussion of DM Proposals

Table C1 reports the percentage of money offers and their acceptance rates by session and treatment and is an expanded version of Table 3 reported on in the main text. The overall acceptance rates are around 40%.

Next we discuss factors that may have contributed to the relatively high rejection rates observed in the DM market. First, we note that we employed a take-it-or-leave-it protocol where the buyer has all the bargaining power. Theory predicts that the buyer proposes a quantity and an amount of tokens awarding the seller a zero surplus, while the buyer receives the whole surplus. That is, theoretically, the seller is indifferent between accepting or rejecting a proposal. This bargaining situation shares some features of the ultimatum game. In contrast with the ultimatum game, however, our setting is dynamic, so computing the surplus associated with a DM proposal requires knowledge of the CM price in the next market. While this is known in the theory, there is more uncertainty in the lab. Further, subjects did not have a chance to fine-tune the proposals, which also may have contributed to generate rejections. In our prior work (Duffy and Puzzello, 2014a), we have shown that if we allow for multiple proposal stages (by keeping the buyer as the last proposer), rejection rates are lower. Overall, in our prior work, we obtained similar results with this implementation as with the one with a single proposal. Since the implementation with multiple proposal stages would take more time and results appear to be robust, in the interest of collecting more data periods, we chose to use the implementation with a single proposal stage for this paper.

Rejections were not necessarily irrational. Table 4 in the paper shows that the better the terms of trade, the higher the probability that a proposal is accepted. In an attempt to better understand rejection rates, we next look at the model-implied surplus associated with the accepted and rejected proposals observed in the data, keeping in mind that there might be departures in the realized surplus as subjects' behavior did not fully follow the model predictions. Nonetheless, if we look at the data through the lenses of the model, we can calculate the seller's surplus associated with a proposal in each pair in period t as

$$-q_t + \phi_t(1 + i_m)d_t,$$

where q_t and d_t denote the quantity and tokens proposed by the buyer, ϕ_t is the inverse of the CM price, i_m=0 in treatments CM, FR-DFL and k-PCT and i_m=0.2 in treatment FR-IOM.

Table C1: Percentage of Money Offers and Acceptance of those Offers, First Half, Second Half and All Periods of Each Sequence, by Session and Treatment

		Percent Money Offers			Percent Accept Money Offers		
Treatment	Ses.	1st Half	2nd Half	All	1st Half	2nd Half	All
Constant M	1	98.94	95.73	97.31	36.81	29.71	33.49
Constant M	2	95.12	88.50	91.71	60.20	42.38	51.27
Constant M	3	91.24	82.18	86.41	32.20	31.75	32.18
Constant M	4	93.20	83.78	88.80	43.72	38.70	41.53
Constant M	5	98.93	86.06	92.57	44.80	42.80	44.00
Average	1-5	95.50	87.34	91.41	43.34	36.91	40.32
FR-DFL	1	92.12	84.10	88.45	43.98	36.84	38.94
FR-DFL	2	99.05	98.67	98.96	47.02	43.14	45.55
FR-DFL	3	95.79	70.87	85.53	51.09	27.83	41.49
FR-DFL	4	96.29	89.02	92.97	33.49	29.44	32.48
FR-DFL	5	93.68	79.04	86.76	50.24	30.60	41.01
Average	1-5	95.34	84.31	90.49	45.03	33.55	39.79
FR-IOM	1	95.56	80.48	89.79	57.56	43.57	51.79
FR-IOM	2	94.90	89.59	92.41	36.79	37.78	37.23
FR-IOM	3	90.75	80.02	85.85	52.88	49.17	50.75
FR-IOM	4	92.75	84.19	88.30	42.78	34.91	39.05
FR-IOM	5	98.10	92.38	95.31	55.24	42.61	49.85
Average	1-5	94.39	85.19	90.27	49.16	41.61	45.80
k-PCT	1	99.13	99.13	99.13	55.99	46.00	51.08
k-PCT	2	100.00	99.05	99.52	53.33	43.81	48.57
k-PCT	3	96.77	98.20	97.70	46.54	38.62	42.86
k-PCT	4	98.21	96.43	97.32	35.27	26.56	30.80
k-PCT	5	100.00	98.33	99.05	33.10	23.10	27.62
Average	1-5	98.81	98.22	98.53	44.95	35.72	40.29
Monetary Equ.		100	100	100	100	100	100

Table C2 below reports the median seller's surplus, by accepted or rejected proposals and by treatment. The seller's surplus is higher for accepted proposals than rejected proposals. Also, note that while the seller's surplus is predicted to be zero in the model, the median surplus tends to be slightly negative in these model-implied computations, an indication that rejections were not irrational. It should also be noted that since subjects' behavior did not fully conform with the theoretical predictions, it is also not necessarily irrational to accept a proposal with negative surplus. For example, a seller in the DM, who is uncertain as to whether he will be able to re-balance his money holdings in the next CM, may agree to a proposal with negative theoretical surplus, as he can acquire money which can be used to trade if he selected as buyer in the future. That is to say, while the surplus is theoretically negative, it may not be empirically so.

Tables C3 and C4 report the median seller's surplus associated with accepted or rejected proposals in early sequences (the first two sequences) and late sequences (sequences greater than 2),

Table C2: Median Seller's Surplus of Accepted and Rejected Proposals, by Treatment

Treatment	Seller's Surplus	
	Accepted Proposals	Rejected Proposals
Constant M	-0.43	-1.88
FR-DFL	0	-1
FR-IOM	-0.11	-1
k-PCT	-1.33	-3.06

by treatment. We find that the median seller's surplus tends to increase between the early part and the later part of the experiment for both accepted and rejected proposals, indicating that subjects are learning over time to make and accept better proposals.

Table C3: Median Seller's Surplus of Accepted Proposals in Early and Late Sequences, by Treatment

Treatment	Seller's Surplus of Accepted Proposals	
	Early Sequences	Late Sequences
Constant M	-0.6	-0.37
FR-DFL	0	0
FR-IOM	-0.32	-0.06
k-PCT	-1.44	-1.27

Table C4: Median Seller's Surplus of Rejected Proposals in Early and Late Sequences, by Treatment

Treatment	Seller's Surplus of Rejected Proposals	
	Early Sequences	Late Sequences
Constant M	-2.64	-1.63
FR-DFL	-1	-1
FR-IOM	-1.77	-1
k-PCT	-4.38	-2.68

We are currently working on designs alleviating rejection rates, e.g., using a centralized market for the DM (as discussed below in section C.7 as well as in Jiang et al., 2019) or a semi-structured time limited bargaining institution (as in Duffy et al., 2021).

C.2 Traded Quantities and Tokens in the DM by Session and Treatment

Table C5 reports the average DM traded quantities and tokens, by session and treatment, and is an expanded version of Table 5 reported in the main body of the paper.

Table C5: Average DM Traded Quantities and Tokens, First Half, Second Half and All Periods of Each Sequence, by Session and Treatment

		Average Traded Quantity			Average Traded Tokens		
Treatment	Ses.	First Half	Second Half	All	First Half	Second Half	All
Constant M	1	4.51	3.55	4.01	7.18	8.27	7.79
Constant M	2	3.52	2.44	3.09	3.55	3.15	3.40
Constant M	3	3.29	1.93	2.49	5.66	2.79	3.90
Constant M	4	4.55	3.59	4.12	4.67	4.13	4.43
Constant M	5	3.95	5.44	4.78	3.61	6.29	5.05
Average	1-5	3.96	3.39	3.70	4.93	4.93	4.91
Monetary Equ.		2	2	2	10	10	10
FR-DFL	1	3.74	2.59	3.06	2.60	0.95	1.80
FR-DFL	2	6.67	4.63	5.82	3.95	2.50	3.33
FR-DFL	3	4.32	2.19	3.54	2.98	1.40	2.34
FR-DFL	4	5.58	3.47	4.75	2.90	1.57	2.36
FR-DFL	5	4.49	1.56	3.06	3.28	1.41	2.39
Average	1-5	4.96	2.89	4.04	3.14	1.57	2.44
Monetary Equ.		9	9	9	7.32	4.26	5.92
FR-IOM	1	4.45	2.91	3.65	4.95	3.23	4.07
FR-IOM	2	4.78	3.60	4.23	4.84	3.06	4.07
FR-IOM	3	2.80	2.61	2.70	2.88	2.90	2.88
FR-IOM	4	3.22	2.17	2.72	4.80	3.56	4.22
FR-IOM	5	5.37	4.48	5.03	5.22	4.45	4.88
Average	1-5	4.13	3.15	3.67	4.54	3.44	4.03
Monetary Equ.		9	9	9	10	10	10
k-PCT	1	4.81	4.78	4.85	7.48	10.91	9.10
k-PCT	2	4.82	6.16	5.42	5.78	9.57	7.50
k-PCT	3	4.28	5.46	4.94	6.91	15.39	10.80
k-PCT	4	3.58	2.78	3.17	9.79	10.72	10.19
k-PCT	5	4.10	4.45	4.29	8.51	11.48	9.67
Average	1-5	4.32	4.73	4.54	7.69	11.61	9.45
Monetary Equ.		0.65	0.65	0.65	12.70	30.65	22.65

C.3 Welfare by Session and Treatment

Table C6 reports average welfare measures by session and treatment, and is an expanded version of Table 7 reported in the main body of the paper.

Table C6: Welfare Relative to the First Best: First Half, Second Half and All Periods of Each Sequence, by Session and Treatment

		Intensive Margin Welfare Relative to First Best			Overall Welfare Relative to First Best		
Treatment	Ses.	First Half	Second Half	All	First Half	Second Half	All
Constant M	1	0.79	0.61	0.71	0.27	0.19	0.23
Constant M	2	0.64	0.59	0.61	0.42	0.25	0.34
Constant M	3	0.62	0.35	0.47	0.21	0.19	0.20
Constant M	4	0.73	0.62	0.68	0.35	0.27	0.31
Constant M	5	0.64	0.56	0.60	0.30	0.28	0.29
Average	1-5	0.68	0.55	0.61	0.31	0.24	0.27
Monetary Equ.		0.62	0.62	0.62	0.62	0.62	0.62
FR-DFL	1	0.67	0.30	0.48	0.32	0.14	0.22
FR-DFL	2	0.83	0.67	0.75	0.41	0.33	0.37
FR-DFL	3	0.72	0.38	0.56	0.38	0.15	0.26
FR-DFL	4	0.73	0.54	0.64	0.27	0.20	0.24
FR-DFL	5	0.65	0.38	0.51	0.35	0.16	0.25
Average	1-5	0.72	0.45	0.59	0.35	0.20	0.27
Monetary Equ.		1	1	1	1	1	1
FR-IOM	1	0.73	0.49	0.61	0.43	0.28	0.35
FR-IOM	2	0.70	0.53	0.61	0.27	0.20	0.23
FR-IOM	3	0.55	0.55	0.55	0.32	0.28	0.30
FR-IOM	4	0.68	0.48	0.58	0.32	0.22	0.27
FR-IOM	5	0.81	0.64	0.72	0.44	0.29	0.37
Average	1-5	0.69	0.54	0.61	0.36	0.25	0.30
Monetary Equ.		1	1	1	1	1	1
k-PCT	1	0.78	0.74	0.76	0.44	0.36	0.40
k-PCT	2	0.77	0.77	0.77	0.42	0.34	0.38
k-PCT	3	0.61	0.71	0.66	0.30	0.28	0.29
k-PCT	4	0.76	0.52	0.63	0.26	0.16	0.21
k-PCT	5	0.75	0.65	0.70	0.25	0.17	0.21
Average	1-5	0.73	0.68	0.70	0.33	0.26	0.30
Monetary Equ.		0.33	0.33	0.33	0.33	0.33	0.33

C.4 Price Levels Over Time by Treatment and Session and Treatment Differences

Table C7 shows mean DM and CM prices over the first half, second half and all periods of each sequence by session and treatment.[36] Table C7 also reports the theoretical predictions for DM and CM prices.[37]

[36] The DM price is constructed by taking the amount of tokens offered d, and dividing it by the quantity, q, produced. The CM price is the ratio of total bids for good X to total units of good X produced.

[37] Since theory predicts that prices decrease in FR-DFL and increase in k-PCT, we used the realized sequence lengths to compute predicted average DM and CM prices in the first half, second half and all periods of each sequence of every session; we then took the average across sessions.

Table C7: Average DM and CM Prices, First Half, Second Half and All Periods of Each Sequence, by Session and Treatment

		DM Prices			CM Prices		
Treatment	Ses.	1st Half	2nd Half	All	1st Half	2nd Half	All
Constant M	1	1.94	2.99	2.48	5.53	8.54	7.10
Constant M	2	1.12	1.47	1.23	1.99	2.98	2.48
Constant M	3	1.76	1.68	1.73	2.16	3.88	3.06
Constant M	4	1.10	1.15	1.12	1.35	1.34	1.35
Constant M	5	1.27	1.17	1.25	1.22	2.60	1.91
Average	1-5	1.44	1.69	1.56	2.45	3.87	3.18
Monetary Equ.		5	5	5	5	5	5
FR-DFL	1	0.96	0.39	0.72	0.58	0.35	0.46
FR-DFL	2	0.59	0.59	0.58	1.52	1.46	1.49
FR-DFL	3	0.68	0.58	0.65	0.63	0.22	0.41
FR-DFL	4	0.52	0.40	0.48	0.62	0.44	0.53
FR-DFL	5	0.89	0.84	0.88	0.77	0.57	0.66
Average	1-5	0.73	0.56	0.66	0.82	0.61	0.71
Monetary Equ.		0.86	0.58	0.66	0.86	0.58	0.66
FR-IOM	1	1.29	1.64	1.36	1.34	1.01	1.18
FR-IOM	2	1.20	0.94	1.07	1.49	2.24	1.87
FR-IOM	3	1.00	1.54	1.27	1.22	1.39	1.30
FR-IOM	4	1.51	1.64	1.55	3.79	3.95	3.83
FR-IOM	5	1.08	1.19	1.12	2.18	1.95	2.08
Average	1-5	1.22	1.39	1.27	2.00	2.11	2.05
Monetary Equ.		1.11	1.11	1.11	1.33	1.33	1.33
k-PCT	1	1.84	2.98	2.30	5.25	27.67	16.48
k-PCT	2	1.31	1.73	1.49	2.13	3.05	2.59
k-PCT	3	1.95	4.03	2.86	2.67	11.41	7.26
k-PCT	4	2.89	7.81	4.94	7.91	16.44	12.07
k-PCT	5	2.22	2.57	2.32	4.87	7.89	6.52
Average	1-5	2.04	3.83	2.78	4.56	13.29	8.98
Monetary Equ.		19.5	47.09	34.85	19.5	47.09	34.85

Figures C1-C4 show time series plots of the mean DM traded prices and CM prices over all rounds of each session of each treatment. Also shown are the equilibrium predictions. Vertical bars indicate the start of a new sequence. Note that the left y-axis which measures DM prices is different in scale from the right y-axis which measures CM prices in each graph. As noted in the text, we see evidence that CM prices fall over the course of a sequence in the FR-DFL treatment and rise over the course of a sequence in the k-PCT treatment, consistent with equilibrium predictions. Mean traded DM prices are also rising over the course of a sequence in the k-PCT treatment, but for the other three treatments the time trend for DM prices is less clear, hence the need for the regression analysis reported in the text.

In Table C8 we report on an OLS regression of all DM and CM prices on dummy variables for the three treatments FR-DFL, FR-IOM and k-PCT; for DM prices, standard errors are clustered at the subject level. The results from the regression provide further evidence that, consistent with Hypothesis 5, prices in both the DM and CM are lower in the FR-DFL and FR-IOM treatments and higher in the k-PCT treatment, relative to the Constant M treatment.

Table C8: OLS Regressions of DM and CM Prices on Treatment Dummies

	DMPrice	CMPrice
Constant	1.413***	3.232***
	(0.083)	(0.390)
FR-DFL	-0.744***	-2.526***
	(0.094)	(0.393)
FR-IOM	-0.158	-1.178***
	(0.108)	(0.412)
k-PCT	0.989***	5.925***
	(0.213)	(1.410)
Observations	1737	623
R^2	0.110	0.118

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

C.5 Money Holdings and Rebalancing

In this section, we consider the extent to which subjects were using the CM to rebalance their money holdings as well as the distribution of those money holdings over time. We first look for evidence that subjects were using the CM to rebalance their money position as of the end of the DM. To address this issue, we first calculate the change in DM money holdings, $\Delta_{DM}m$, as the difference between beginning of period money holdings and end of DM round money holdings. For the FR-DFL, FR-IOM and k-PCT treatments, the beginning of period DM money holdings are *after* tax or subsidy, respectively. The change in CM money holdings, $\Delta_{CM}m$, is the difference between end of DM round money holdings and end of CM round money holdings with one exception: for the FR-IOM treatment, we include the proportional interest payment of 20 percent in the end of DM money holdings as these additional tokens were available to subjects at the start of the CM.

Table C9 reports on a regression of the change in CM money holdings on DM money holdings for each of the four treatments.

The significantly negative coefficient on $\Delta_{DM}m$ in all four treatments provides evidence that subjects were using the CM to rebalance their money holdings. This rebalancing was less then perfect as the coefficient on $\Delta_{DM}m$ is significantly different from -1. This finding is comparable to what is reported in Duffy and Puzzello (2014). In three of the four treatments, the constant term is not significantly different from zero indicating no bias in CM money changes. For the FR-IOM

Table C9: Regression Evidence for Rebalancing in the CM

	Constant M	FR-DFL	FR-IOM	k-PCT
	$\Delta_{CM}m$	$\Delta_{CM}m$	$\Delta_{CM}m$	$\Delta_{CM}m$
$\Delta_{DM}m$	-0.534***	-0.408***	-0.512***	-0.630***
	(0.082)	(0.051)	(0.066)	(0.086)
Constant	0.000	-0.000	-1.024***	0.000
	(0.196)	(0.117)	(0.181)	(0.802)
Observations	2184	2184	2184	2184
R^2	0.094	0.085	0.159	0.065

Robust standard errors clustered at the subject level in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

treatment, the constant term is significantly negative, which indicates that changes in CM money holdings were reduced on average by 1 token relative to changes in DM money holdings. We suspect that this bias was due to the 20 percent interest payments that subjects received at the start of the CM in the FR-IOM treatment only. This may reflect some "money illusion" on the part of some subject in the FR-IOM treatment.

Regarding the distribution of money holdings, recall that our assumptions on the utility and cost functions imply that the predicted distribution of money holdings is unique *and* degenerate at $\frac{M}{2N}$. In the case of the constant M and FR-IOM treatments, the money stock M is fixed at 140 and $2N$ is always 14, so the predicted per capita money holdings should always be 10 following the rebalancing of the CM. In the FR-DFL and k-PCT treatments, the money stock changes over time, decreasing in the former and increasing in the latter, so that the degenerate, per capita money holdings should be $\frac{M_t}{2N}$ in periods $t = 1, 2, ...$, where $M_t = 140(1 + k)^{t-1}$, and where $k = -1/6$ in the FR-DFL treatment and $k = 1/6$ in the k-PCT treatment. We do not find evidence for degeneracy in the distribution of money holdings in any of our treatments. However, we do find some evidence that money holdings are clustered around the per capita predictions –see the next section for details.

C.6 Distribution of Money Holdings

Here we report on the distribution of money holdings at the beginning of the DM across all four treatments (except for the first period, where money holdings are given). For the Constant M and FR-IOM treatments, the money supply is constant and so the distribution of token holdings should be degenerate at 10 tokens per subject. Figures C5-C6 show the distribution of per capita money holdings at the start of the DM of these two treatments. The distributions are divided up between the first and second halves of each sequence of all sessions of each treatment. As these figures reveal, in the first half of each sequence, per capita token holdings are more closely concentrated but are not degenerate at 10. In the second half of each sequence, the per capita token holdings become more diffuse.

For the other two treatments, the aggregate money supply decreases or increases depending on the rule in place. Therefore we report the distribution of money holdings at two different periods in a sequence to give a sense of how per capita money holdings change over time. In particular, we report on the distribution of money holdings in the second period and in the fourth period (conditional on those periods being reached) across all sessions of the FR-DFL and k-PCT treatments. Figure C7 shows the distribution of money holdings for periods 2 (left panel) and 4 (right) panel of the FR-DFL treatment, while Figure C8 does the same for the k-PCT treatment.

For the FR-DFL treatment, token holdings in period 2 should be degenerate at 8.33 and in period 4 they should be degenerate at 4.82. As Figure C7 reveals, the distributions are not degenerate at these predicted levels but the distribution is moving to the left from period 2 to period 4, and becomes more dispersed in the later period.

For the k-PCT treatment, token holdings in period 2 should be degenerate at 11.67 and in period 4 they should be degenerate at 15.88. While again, there is no support for the prediction that the distribution of token holdings is degenerate at these two numbers, we see that the per capita token holdings are shifting to the right from period 2 to period 4 and are becoming widely dispersed in the later period 4 as compared with the earlier period 2.

C.7 Experiments with a Centralized DM

A puzzling finding is that we do not observe much deflation or inflation in the DM of the FR-DFL and k-PCT treatments, respectively. By contrast, we did observe deflation or inflation in the CM of these two treatments–see Table 9. One explanation for this difference is that in the DM, prices are specific to each pair, and no-trade outcomes are frequent. Consequently, price signals may be weaker in the DM as compared with the CM where all players participate in determining the market price and all see the same CM price. This observation led us to consider a different version of our model where the price formation mechanism in the DM is replaced by a market game of the same type used in the CM.[38] We retain the gains from trade in the DM by partitioning subjects randomly into consumers or producers in each period. Consumers decide how many of their tokens to bid for units of the DM good and producers decide how many units to produce. The single DM market price is determined in the same manner as in the CM, by the ratio of the amount bid by all consumers divided by the amount produced by all producers and all exchanges take place at this single market price. Otherwise, the environment is the same and so the steady state predictions of the model also remain unchanged (since in the previous experiments we use a take-it-or-leave-it bargaining protocol and the cost function in the DM of those experiments is linear). Rather than referring to the markets as the DM and CM, in these new experimental sessions, we refer to them as market 1 and market 2, as both markets are now centralized. Replacing the bilateral bargaining in market 1 with a single centralized market price may help monetary policy to have more impact on deflation or inflation of the price level and therefore on welfare.

Using this different, two centralized markets design, we conducted one session of each of our four treatments using the same procedures and the same sequence lengths used in session 1 of each of those treatments (as shown in Table 2). Each of these four new sessions involved 14 new subjects with no prior experience in our other treatments (for a total of $14 \times 4 = 56$ additional subjects). The instructions for these four new sessions were modified to explain the centralized market in the

[38] Both decentralized and centralized trading institutions have been considered in the literature. See, e.g., Rocheteau and Nosal (2017). Furthermore, Camera et al. (2016) study monetary exchange when agents can choose the market structure. They find that if the group size is large enough, subjects coordinate on the use of centralized as opposed to decentralized markets.

first round of each two-round period (the former DM).[39]

With this change in design, we now observe that there *is* deflation in the FR-DFL treatment and inflation in the k-PCT treatment in *both* markets 1 and 2 as shown in Table C10, even though they are less pronounced in market 1 than in market 2. Recall that in our original experimental design, we did not observe such deflation or inflation of prices in the DM (market 1) of those two treatments. Table C11 reveals that there is little or no changes in prices in the two markets of the Constant M or FR-IOM treatments as we also found previously. Overall welfare, relative to the first best, is higher for all treatments as compared with our prior experiment as can be seen by comparing Figure C9 with Figure 3. However, we continue to find that welfare is lower in the two Friedman rule treatments as compared with the Constant M and k-PCT treatments as shown in Figure C9. The change in market 1 institution does reduce the incidence of consumers with zero money holdings relative to the bilateral bargaining setting as revealed in Figure C10, but this reduction in liquidity constrained consumers does not suffice to improve welfare in the two Friedman rule treatments. We continue to find that consumers are more generous with their bids in the k-PCT treatment where they have more tokens on average, and least generous in the FR-DFL treatment where they have the least tokens on average as shown in Table C12. While in this study the trading institution in market 1 does not appear to affect the impact of the monetary policies that we consider, another study by Jiang et al. (2019) which focuses exclusively on inflationary policies in an environment with centralized markets, fixed roles of buyers and sellers and a different timing of monetary injections, finds results that are aligned more closely with theoretical predictions. We leave a more exhaustive study of the role that market structure plays for the transmission of monetary policies to future research.

Table C10: Market 1 and Market 2 Prices Over Time, FR-DFL versus k-PCT

	FR-DFL MKT1	FR-DFL MKT2	k-PCT MKT1	k-PCT MKT2
Period within a Sequence	-0.084***	-0.102***	0.191***	0.193***
	(0.007)	(0.005)	(0.014)	(0.005)
Constant	0.774***	1.128***	0.011	0.360***
	(0.047)	(0.029)	(0.065)	(0.031)
Observations	33	33	33	33
R^2	0.186	0.515	0.344	0.812

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

[39]Copies of the instructions used in these four new treatments can be found at: `https://www.socsci.uci.edu/~duffy/MonetaryPolicy/`.

Table C11: Market 1 and Market 2 Prices Over Time, Constant M versus FR-IOM

	Constant M MKT1	Constant M MKT2	FR-IOM MKT1	FR-IOM MKT2
Period within a Sequence	-0.001	0.078***	0.056***	0.052***
	(0.010)	(0.006)	(0.009)	(0.005)
Constant	-0.021	-0.025	0.319***	0.537***
	(0.047)	(0.039)	(0.056)	(0.032)
Observations	32	32	33	33
R^2	0.000	0.134	0.078	0.198

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table C12: Regression of Consumer's d/m_c on treatment dummies controlling for the quantity traded

	d/m_c
Constant	0.462***
	(0.046)
FR-DFL	-0.014
	(0.058)
FR-IOM	-0.092
	(0.061)
k-PCT	0.150**
	(0.065)
Traded q	0.021***
	(0.003)
Observations	886
R^2	0.194

Standard errors clustered at the subject level in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

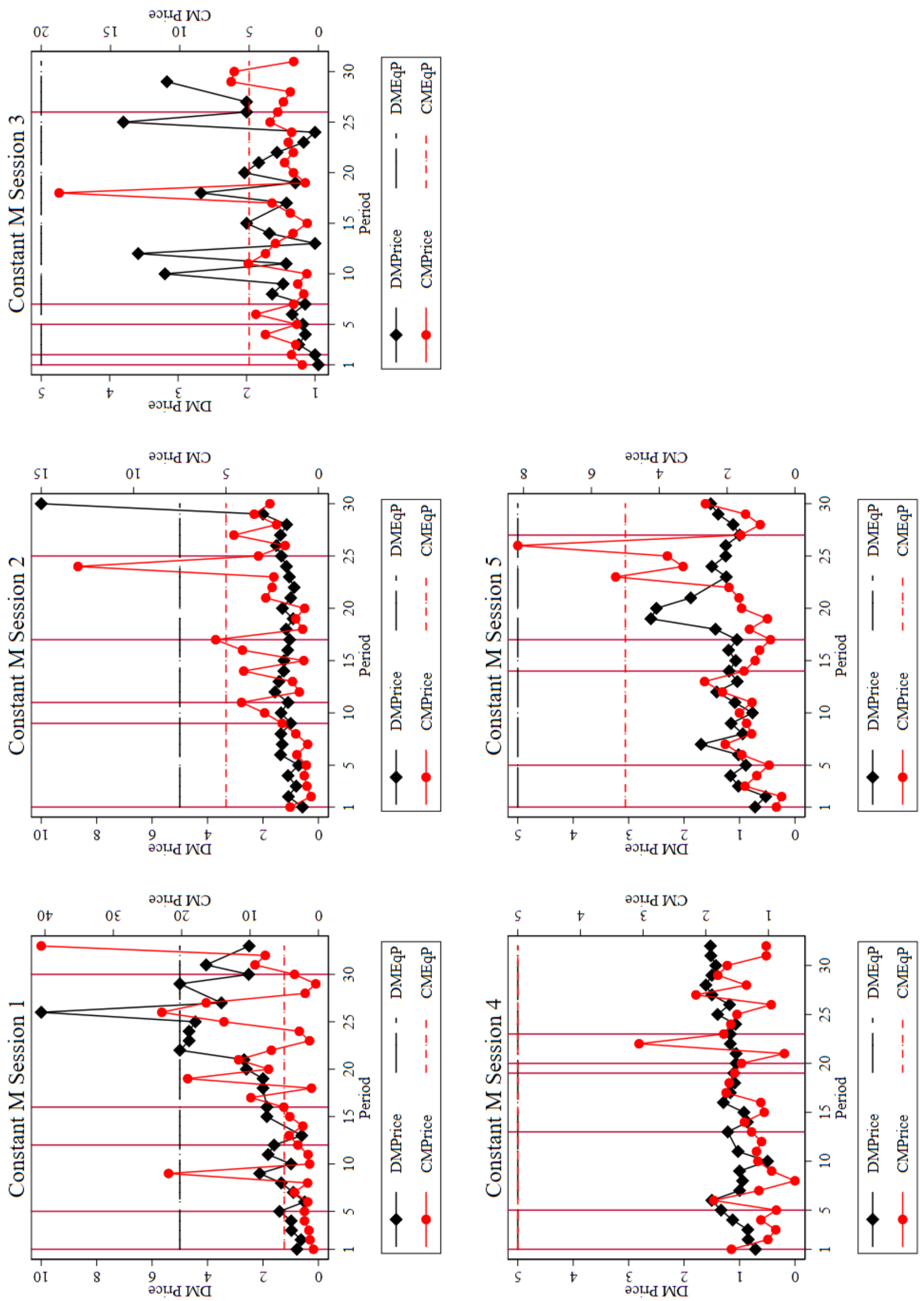

Figure C1: Mean DM Prices and CM Prices over time compared with Equilibrium Predictions, 5 Sessions of the Constant M treatment

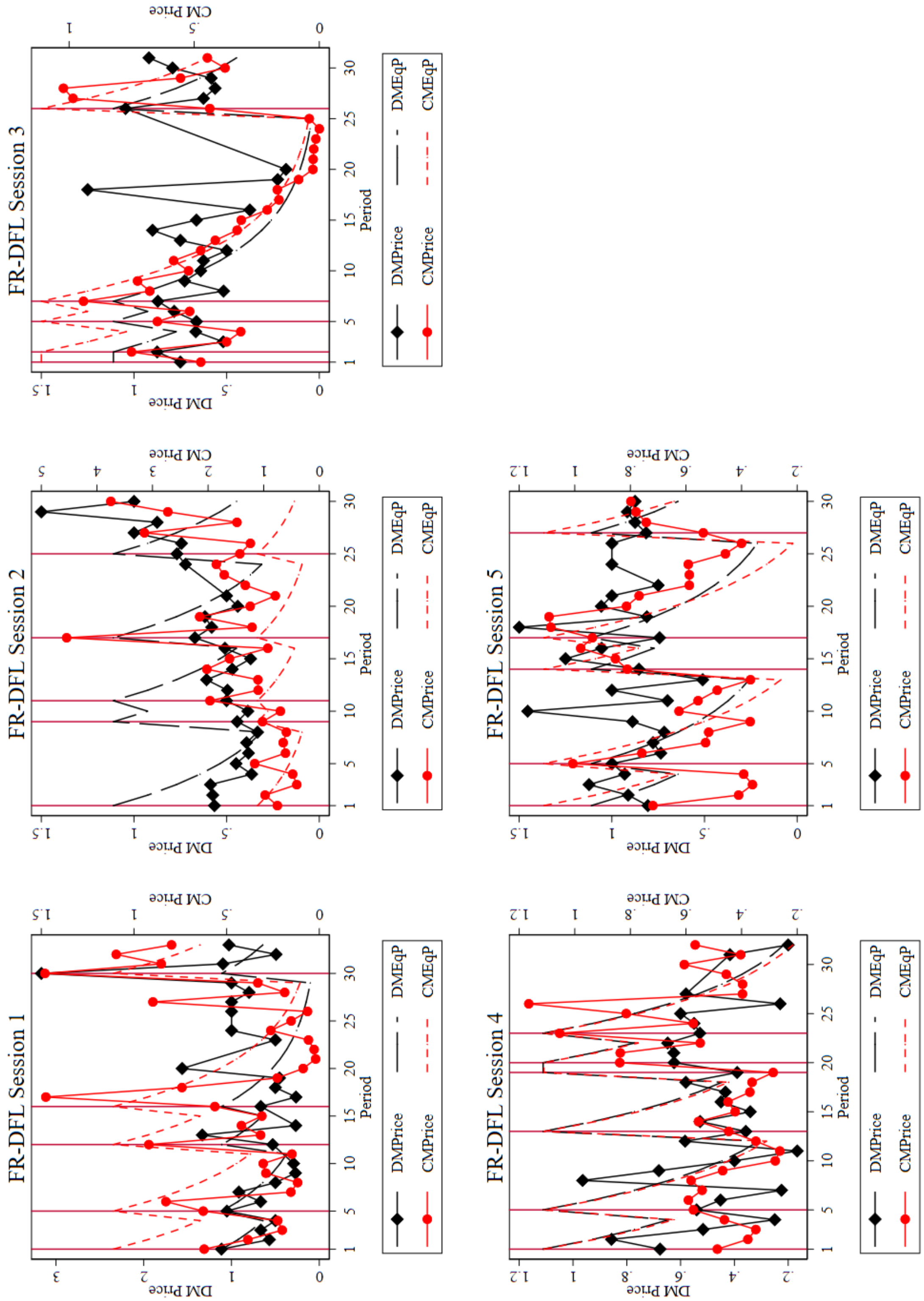

Figure C2: Mean DM Prices and CM Prices over time compared with Equilibrium Predictions, 5 Sessions of the FR-DFL treatment

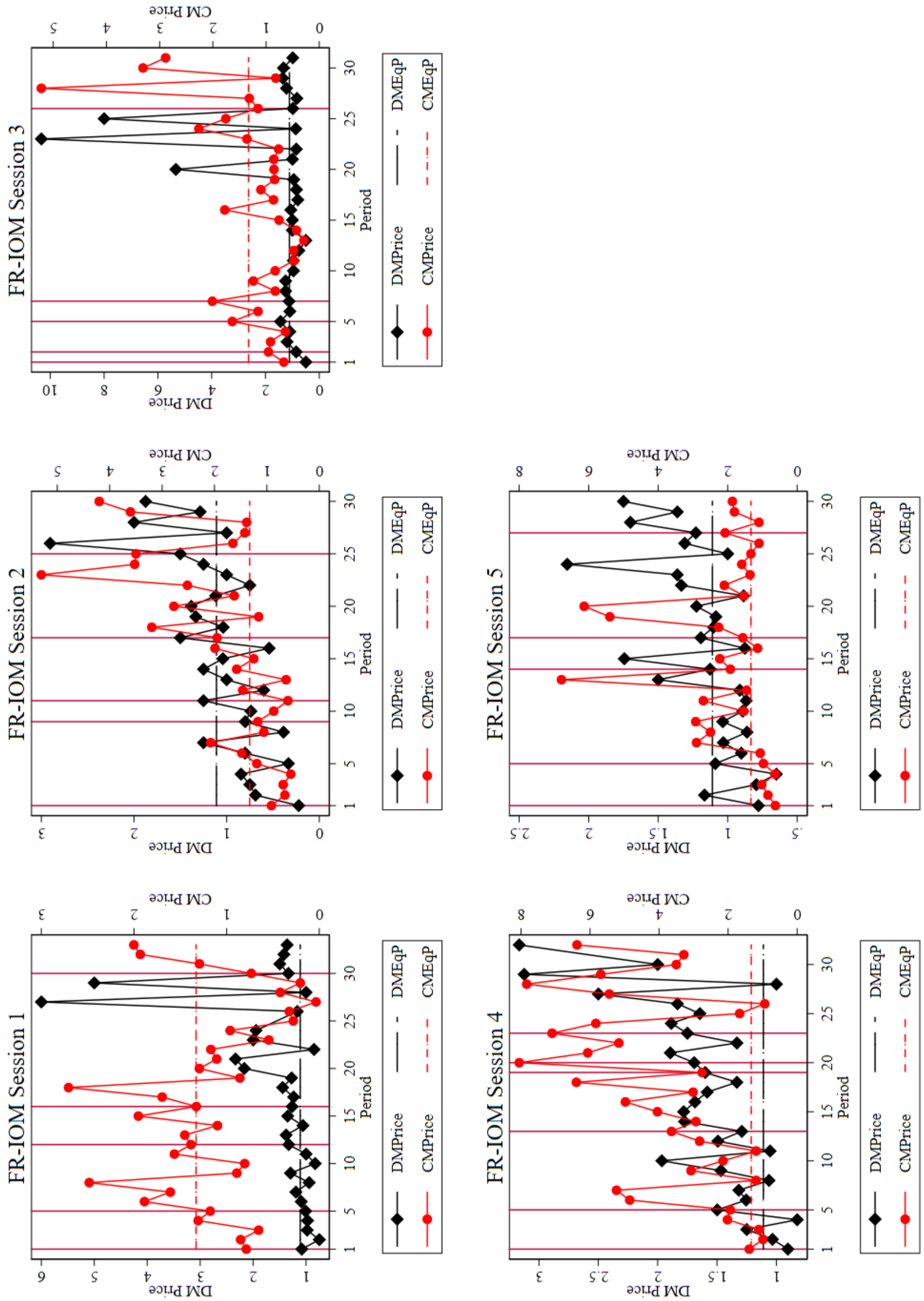

Figure C3: Mean DM Prices and CM Prices over time compared with Equilibrium Predictions, 5 Sessions of the FR-IOM treatment

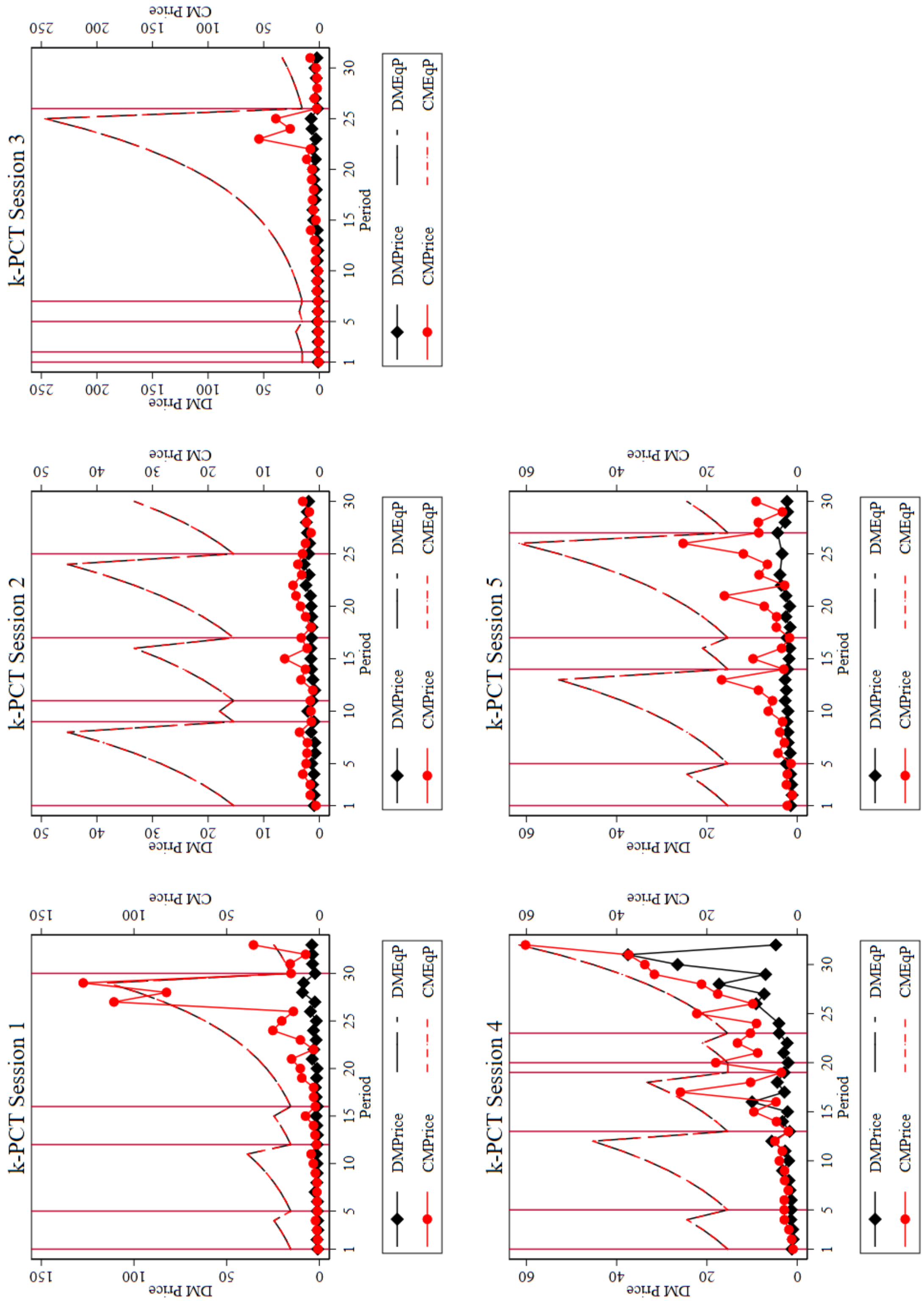

Figure C4: Mean DM Prices and CM Prices over time compared with Equilibrium Predictions, 5 Sessions of the k-PCT treatment

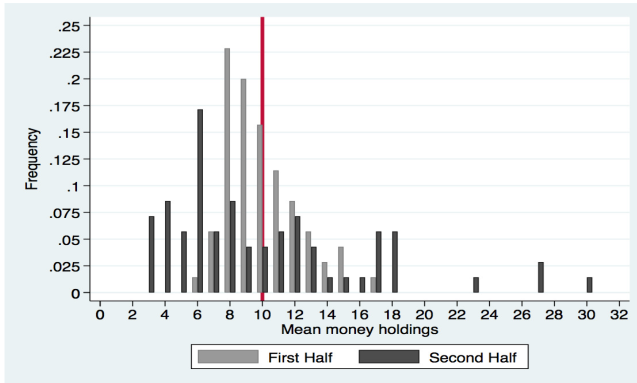

Figure C5: Distribution of Money Holdings, Constant M Treatment, First Half vs. Second Half of Each Sequence

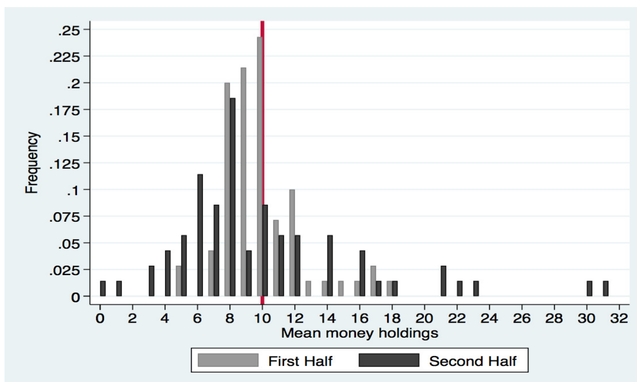

Figure C6: Distribution of Money Holdings, FR-IOM Treatment, First Half vs. Second Half of Each Sequence

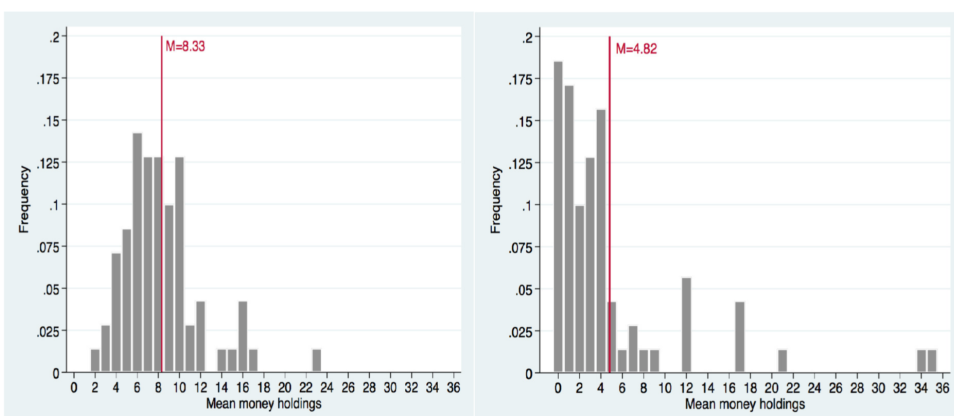

Figure C7: Distribution of Money Holdings, FR-DFL Treatment, Period 2 (left panel) vs. Period 4 (right panel) of Each Sequence

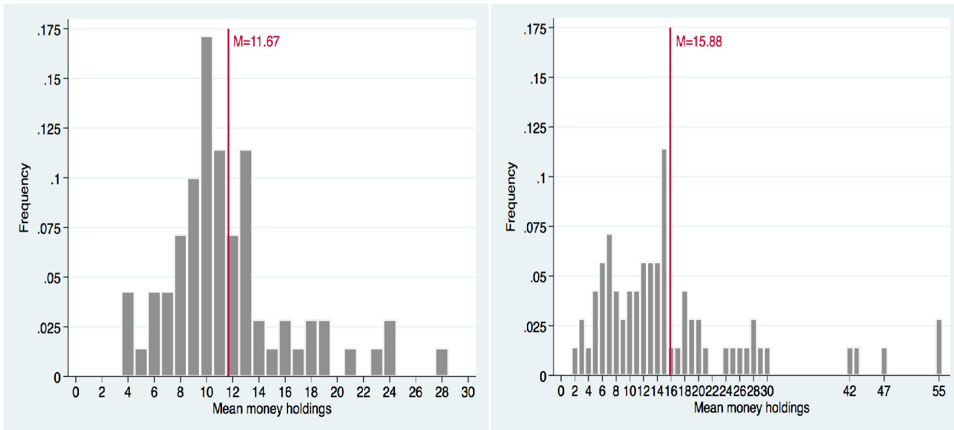

Figure C8: Distribution of Money Holdings, k-PCT Treatment, Period 2 (left panel) vs. Period 4 (right panel) of Each Sequence

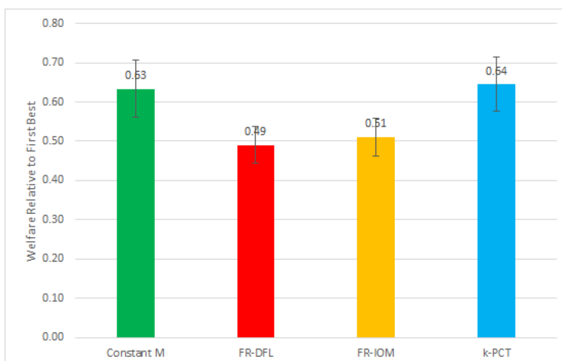

Figure C9: Overall Welfare Ratio to First Best and 95% Confidence Interval

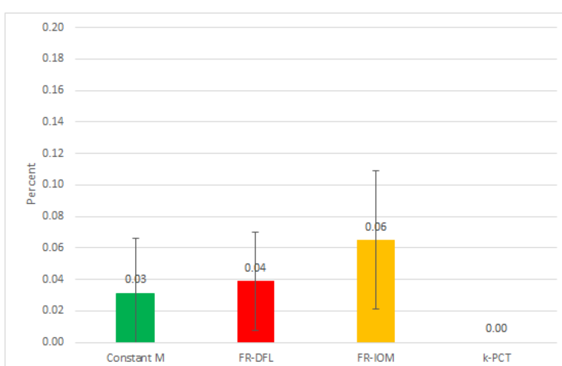

Figure C10: Percentage of Market 1 Consumers with 0 Tokens by Treatment with 95% Confidence Intervals