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THE FRIEDMAN RULE: EXPERIMENTAL EVIDENCE*

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We evaluate the Friedman rule for optimal monetary policy in a laboratory economy based on Lagos–Wright (*Journal of Economic Theory* 145 (2010), 1508–24). We explore two implementations of Friedman's rule: one involving deflationary monetary policy and another where interest is paid on money. We compare the welfare consequences of the Friedman rule with two other policies: a constant money supply regime and a regime where the money supply grows at a constant k%. Counter to theory, we find that the Friedman rule is not welfare-improving, performing no better than the constant money regime. By one welfare measure, the k% money growth rate regime performs best.

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 0. Since the nominal interest rate represents the private marginal cost of holding money, and the marginal cost of producing money is essentially 0, 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 0.

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, p. 1068). Indeed, the Friedman rule has played such an important role in monetary theory that we believe that 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

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[1] Although 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 et al. (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 ignores. However, even in models with sticky prices and money demand, the optimal policy has been shown to involve an inflation rate that

different implementations of the Friedman rule, we consider a constant money supply rule and a $k\%$ 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 workhorse model in monetary economics and it is amenable to laboratory implementations. Specifically, it is an explicitly microfounded, 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 rebalance 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. Without such an explicit, microfounded 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 $\pi = -\rho < 0$, which 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 have likely rendered this possibility impractical (though the U.S. Federal Reserve has paid interest on bank reserves since October 2008). In this article, 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 that serves as our control treatment. The second is a constant money growth rate regime where the money supply grows at a fixed and known $k\%$ 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

lies somewhere between the Friedman rule (deflation) and 0, see, for example, Khan et al. (2003), Schmitt-Grohé and Uribe (2004), and Aruoba and Schorfheide (2011).

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

[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 Subsection 4.1.

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 $k\%$. 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.

2. RELATED LITERATURE

This article contributes to a literature that uses experiments to study monetary economics and policy (see Duffy, 2016, 2021, for surveys). Most relevant to this article are experiments that have considered the impact of monetary policies 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. (2021), Bernasconi and Kirchkamp (2000), Cornand and M'Baye (2018), Deck et al. (2006), Duffy and Heinemann (2021), Fenig et al. (2018), Hommes et al. (2019), Kryvtsov and Petersen (2021), Jiang et al. (2021b), 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, although in this article, 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 nonmonetary gift-exchange equilibria in addition to the monetary equilibrium; these gift exchange equilibria are supported by a contagious grim-trigger strategy played by the society of agents as a whole (see, e.g., Kandori, 1992). Some of these gift-exchange equilibria Pareto-dominate the monetary equilibrium, implying that money may fail to be essential (see, e.g., Araujo, 2004; Aliprantis et al., 2007a, 2007b; Araujo et al., 2012). However, we found that subjects avoid nonmonetary gift-exchange equilibria in favor of

[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.

coordinating on the monetary equilibrium. Duffy and Puzzello also study versions of the model when money is not available (see Aliprantis et al., 2007a, 2007b and Araujo et al., 2012) and find that welfare is significantly higher in environments with money than without money, suggesting that money plays a key role as an efficiency-enhancing coordination device.

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. 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 et al. (2013) and Camera and Casari (2014) also compare outcomes across two environments, with fiat money ("tickets") and without fiat money. In their repeated game, money is not essential to achieve the Pareto-efficient outcome that 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. (2020) 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 et al. (2021a) also study the essentiality of money in *finite-horizon* environments. They show that production rates and efficiency are higher when monetary exchange is an equilibrium. They also show that, as subjects gain experience, the suggestion to use fiat money increases production rates only when it is an 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 et al.'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 the online 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 $t = 1, 2, \ldots$ Each agent enters a period holding some nonnegative amount of an intrinsically worthless and inconvertible object referred to as fiat money, which is both divisible and durable. Let $(m_t^1, m_t^2, \ldots, m_t^{2N})$ 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 then 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 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 DM round). That is, they decide how much to sell or buy in the Walrasian market 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 CM 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 CM 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 $u'(q^*) = c'(q^*)$, that is, q^* is the first best as it maximizes surplus in a pair. Also, let $\bar{q} > 0$ be such that $u(\bar{q}) = c(\bar{q})$. In what follows, we focus on stationary equilibria, that is, $\phi_t M_t = \phi_{t+1} M_{t+1}$.

The periodic access to the CM in conjunction with the quasi-linearity of preferences delivers tractability and thus a closed-form solution for the monetary equilibrium. Following the same steps as in Lagos and Wright (2005) (see also the online 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 DM (or savings), m_{t+1}^i, solves a sequence of simple static optimization problems:

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

[5] See also Lagos et al. (2017) for a discussion of the advantages of this framework.

[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.

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 $\beta\frac{1}{2}[u(q_{t+1}(m^i_{t+1}) - (1+i_m)\phi_{t+1}d_{t+1}(m^i_{t+1})]$ 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 $\frac{\phi_t}{\phi_{t+1}} = \mu = \beta(1+i_m)$, that is, the Friedman rule. Also, note that under the Friedman rule, the opportunity cost of holding money is 0.

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 $V = \frac{1}{1-\beta}\{\frac{1}{2}[u(\widetilde{q}) - c(\widetilde{q})]\}$.

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 deflation (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, 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 interest on money (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, that is, $\mu = \beta(1+i_m) = 1$. 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% 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% 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 0 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 instead of the autarkic equilibrium:

Hypothesis 1. The monetary equilibrium instead of 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 $k\%$ 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% 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% 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 DM round and the CM round.

In the first 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%. 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 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 rebalancing of money holdings. As in Duffy and Puzzello (2014a), the market for the homogeneous good X is implemented using a Shapley and 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, she/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, she/he specifies the number of units of good X, Q_i she/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 CM 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 CM 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 $\{1, \ldots, 6\}$ 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 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

[10] Although 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 noncooperative game-theoretic foundations for price-taking behavior in sufficiently large populations. As Duffy et al. (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 that it is desirable to have prices endogenously determined.

[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 or with uncertainty in the last position that avoid unraveling due to backward induction (see, e.g., Cooper and Kühn, 2014; Fréchette and Yuksel, 2017; Davis et al., 2020; Jiang et al., 2021a). Jiang et al. (2021c) 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.

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 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, that is, 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 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, "token poor" subjects were asked to produce units of the CM good at the most recently determined CM price 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 of period 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% *Rule Treatment.* Our final treatment involves the constant $k\%$ money rule, also advocated by Friedman, even though it is not theoretically optimal for the baseline economy. We implemented the $k\%$ 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 $k\%$ 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 $\beta = 5/6$ (0.83) as in our earlier work (Duffy and Puzzello, 2014a,b). The DM utility function is a constant relative risk aversion (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 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 $M_1 = 140$.

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 that 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% 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% 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% interest payment was provided by a *lump-sum tax* of two 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, $k\%$ 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,

[12] In Duffy and Puzzello (2014a,b), 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 article.

[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%, to make the theoretical predictions discernible across our four treatments given the noisy nature of experimental data.

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

where welfare is also predicted to be the highest across the four treatments.[14] Welfare is lowest in the k% monetary policy regime. The last two columns provide welfare comparisons in absolute terms as well as relative to the first best. Specifically, column 6 provides the expected lifetime payoff under each treatment. In column 7, we provide the welfare ratio relative to the first best, that is, 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]

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 that 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 B. 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 five 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 is 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

[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 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. (2020) and Jiang et al. (2021a) for theory and experiments in finite-horizon economies where money is valued.

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

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 of two rounds. In the first round (the 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 (i) produce the CM good X, (ii) consume the CM good X, (iii) do both, or (iv) 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

[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.

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

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	First Half	Second Half	All	First Half	Second Half	All
Constant M	96.17	87.54	91.72	44.15	38.11	41.03
FR-DFL	95.51	87.16	91.58	45.51	35.78	40.93
FR-IOM	94.57	88.24	91.47	49.50	43.28	46.45
k-PCT	99.23	98.61	98.90	45.75	36.06	40.66
Monetary Equ.	100	100	100	100	100	100

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

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 peri-

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

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

[22] Most consumers, between 84% and 100% on average across treatments, enter the DM with positive token holdings. If we included consumers without any money holdings, we would find lower frequencies of money offers,

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 > χ^2	0.000	0.000

NOTES: Standard errors in parentheses

$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

ods, 90% 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% (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% acceptance rates of *money* offers that we observe in this experiment are in line with our earlier experimental results (Duffy and Puzzello, 2014a,b) and are explained below by the offer terms that producers faced when deciding whether or not to accept consumers' offers (see the online 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

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 take it or leave it 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 article.

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

TABLE 5
AVERAGE DM-TRADED QUANTITIES AND TOKENS, FIRST HALF, SECOND HALF, AND ALL PERIODS OF EACH SEQUENCE, BY TREATMENT

Treatment	Average Traded Quantity			Average Traded Tokens		
	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

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 DMs over the first half, second half, and all periods of each sequence, by treatment, along with equilibrium predictions (see Table C5 in the online Appendix C 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 FR-IOM version.[26]

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% 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

[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.

[26] These findings are largely unchanged if we consider average *proposal* quantities instead of 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. Although 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.

[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, whereas in Table 5, means are first averaged by period and then by first half, second half, or all periods of a sequence.

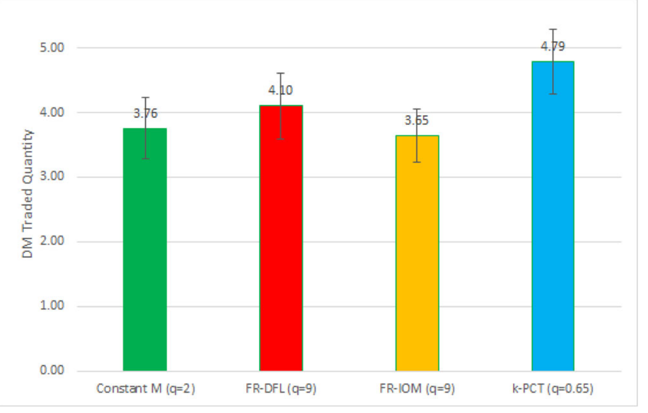

FIGURE 1

MEAN DM-TRADED QUANTITY ACROSS TREATMENTS WITH 95% CONFIDENCE INTERVALS. MONETARY EQUILIBRIUM PREDICTIONS IN PARENTHESES [COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

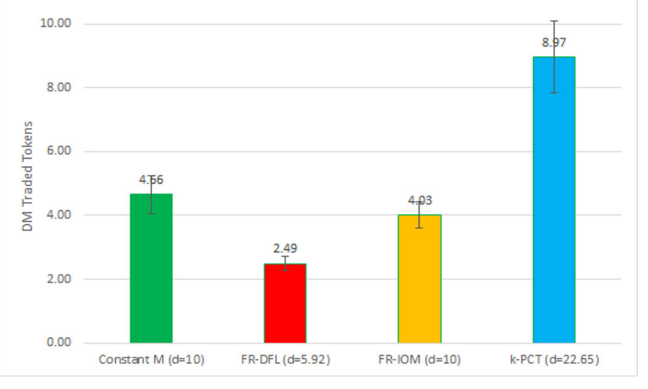

FIGURE 2

MEAN DM-TRADED TOKENS ACROSS TREATMENTS WITH 95% CONFIDENCE INTERVALS. MONETARY EQUILIBRIUM PREDICTIONS IN PARENTHESES [COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

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

NOTES: 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.

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.

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 welfar—overall welfare—amounts to computing the sum of the surpluses across pairs in the DM round of each period. We 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% of proposals are accepted on average. The theory predicts 100% acceptance rate regardless of the monetary regime. That is, in theory, monetary policies should not affect the extensive margin, that is, whether trade occurs or not. Instead, monetary policy impacts only the intensive margin, that is, 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) 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% 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 in these ratios across all four treatments.

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

[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 (third column) since the DM prices is calculated as d/q.

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

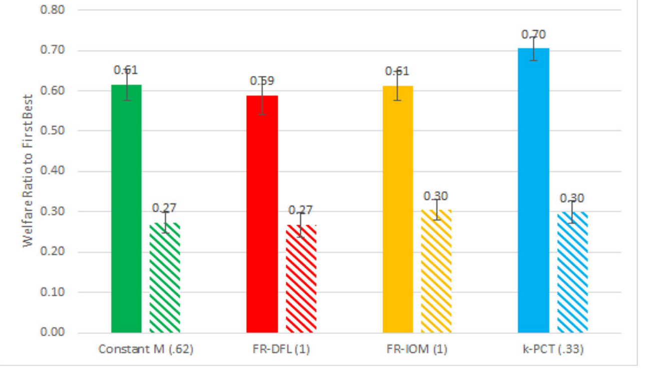

FIGURE 3

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 [COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

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 ($p < 0.01$ 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 Subsection 5.6.

The second regression using the overall welfare measure shows that welfare is marginally higher 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 ($p = 0.0815$). 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%. 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

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

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

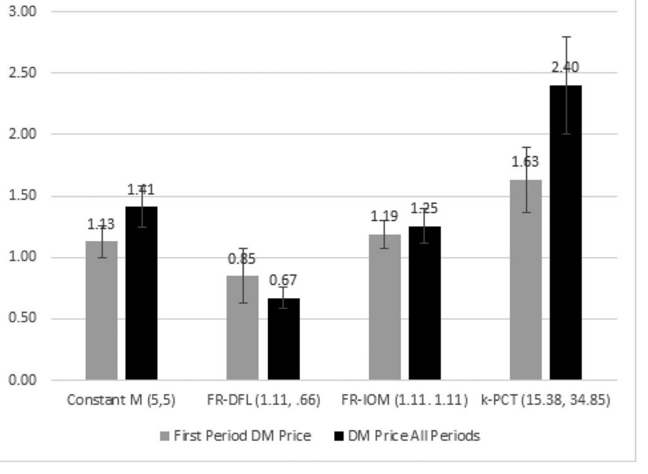

FIGURE 4

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)

along with 95% confidence interval bars. The first bar in these figures shows the mean DM or CM prices in the first period of each new sequence, whereas 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 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% increase in the money supply from interest payments. Again, we see in Figure 5 qualitative

[29] Table C7 in the online 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.

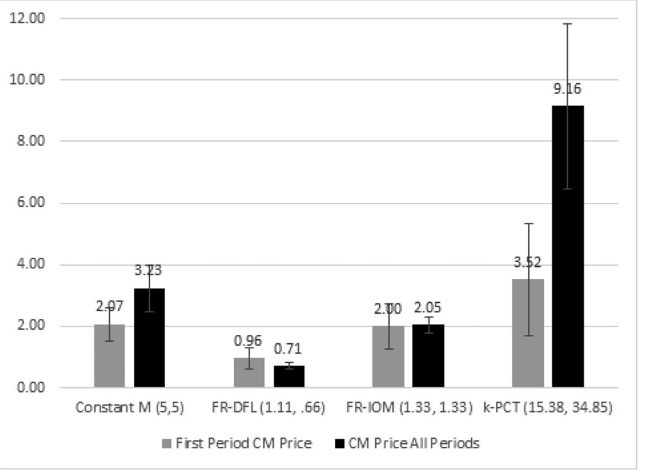

FIGURE 5

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)

support for the predictions, though again, the data are generally different from the precise level predictions.[30]

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, whereas 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 the online 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% over time, whereas in the k-PCT treatment, the inflation rate of both the DM and CM price should be 16.67% 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 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, whereas 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 ($p = 0.184$). 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 ($p = 0.052$) 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

[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.

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

NOTES: 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

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

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% and CM prices in the k-PCT treatment increased at a rate of 20%, which are close to the predicted 16.67% decline or increase, respectively. However, DM prices did not appear to respond appropriately to changes in the money supply. A more direct test

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

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

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 (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.

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 underreact 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 overreact 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: (i) liquidity constraints and (ii) 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 the online 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 rebalance 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.

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

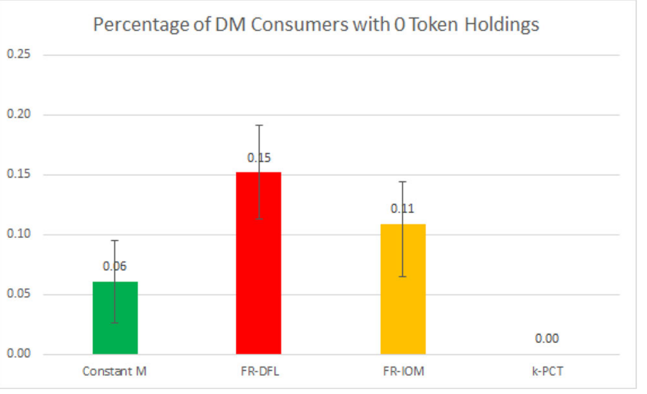

FIGURE 6

PERCENTAGE OF DM CONSUMERS WITH 0 TOKENS BY TREATMENT WITH 95% CONFIDENCE INTERVALS [COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

Figure 6 provides support for this conjecture. We observe that 15% of consumers in the FR-DFL and 11% 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 rebalance 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 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

[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.

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

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

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.

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, for example, 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. Although 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, microfounded 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%, which bears closest resemblance to our k-PCT treatment. Indeed, one can perhaps view the main message of our article 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. (2021b) consider the k-PCT rule and other inflationary policies with CMs and fixed roles in both markets. Another possibility would be to automate the CM to facilitate the necessary rebalancing 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, for example, open market operations. We think that laboratory experiments are a natural complement to theoretical and empirical analyses of the impact of monetary policy using nonexperimental field data. Our article provides evidence that such experiments are both possible and informative.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Figure 1: Consumer Decision Screen, Decentralized Market
Figure 2: Producer Decision Screen, Decentralized Market
Table 1: Benefits and Costs (in Points) for Consumers and Producers, Decentralized Meeting
Figure 3: Decision Screen, Centralized Meeting
Table 2: Benefit and Cost (in Points) for Consumers and Producers, Centralized Meeting
Table 3: Token Tax Calculations Following the Centralized Meeting
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
Table C2: Median Seller's Surplus of Accepted and Rejected Proposals, by Treatment
Table C3: Median Seller's Surplus of Accepted Proposals in Early and Late Sequences, by Treatment
Table C4: Median Seller's Surplus of Rejected Proposals in Early and Late Sequences, by Treatment
Table C5: Average DM Traded Quantities and Tokens, First Half, Second, Half and All Periods of Each Sequence, by Session and Treatment
Table C6: Welfare Relative to the First Best: First Half, Second Half, and All Periods of Each Sequence, by Session and Treatment
Table C7: Average DM and CM Prices, First Half, Second Half, and All Periods of Each Sequence, by Session and Treatment
Table C8: OLS Regressions of DM and CM Prices on Treatment Dummies
Table C9: Regression Evidence for Rebalancing in the CM
Table C10: Market 1 and Market 2 Prices Over Time, FR-DFL versus k-PCT
Table C11: Market 1 and Market 2 Prices Over Time, Constant M versus FR-IOM
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 versus Second Half of Each Sequence
Figure C6: Distribution of Money Holdings, FR-IOM Treatment, First Half versus Second Half of Each Sequence
Figure C7: Distribution of Money Holdings, FR-DFL Treatment, Period 2 (left panel) versus Period 4 (right panel) of Each Sequence
Figure C8: Distribution of Money Holdings, k-PCT Treatment, Period 2 (left panel) versus 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
Table C12: Regression of Consumer's d/m_c on Treatment Dummies Controlling for the Quantity Traded
dataprogramme

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