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Money, inflation tax, and trading behavior: Theory and laboratory experiments ☆

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ABSTRACT

In a Kiyotaki-Wright model, we generate equilibria characterized by the partial or full acceptability of fiat money and by fundamental or speculative trading strategies. In a laboratory setting with real participants, we then test the model's predictions regarding the effects of an inflation tax and the quantity of money on production and welfare. The inflation tax is implemented through the confiscation of money holdings. Consistent with the model's prediction, the inflation tax reduces the frequency at which players trade a low-storage cost good for fiat money. However, contrary to the model's prediction, we did not observe any significant influence of the inflation tax on trading strategies, suggesting that the inflation tax causes only modest production distortion. We also find that the acceptance of money in the lab is not correlated with the proportion of people holding money. We discuss the welfare consequences of the inflation tax and relate them to the experimental findings based on New Monetarist models.

1. Introduction

The recent monetary expansion in many advanced countries has reignited interest among scholars and policymakers in understanding the effect of money creation and inflation on individuals' purchasing and trading behaviors, and how these responses are transmitted to the macroeconomy. A common concern is that inflation can lead to socially wasteful activities as individuals attempt to shift the inflation tax onto others (see, among others, Lucas, 2000; Lagos and Rocheteau, 2005; and Cooley and Hansen, 1989). Another concern is the redistributive effects of inflation, which disproportionately affects individuals with a larger share of their wealth in cash and those employed in cash-intensive sectors.

In this paper, we explore individuals' trading reactions to money and to an inflation tax, and the resulting aggregate productivity and welfare effects, within an extension of Kiyotaki and Wright (1989, henceforth KW). In this setup, the response of producers,

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consumers, and traders to monetary policy is on the extensive margin: depending on the quantity of money in circulation and the level of the inflation tax, agents can coordinate on a speculative equilibrium, characterized by elevated aggregate productivity, or on a fundamental equilibrium with lower aggregate productivity. Unlike cash-in-advance models in the vein of Lucas (2000), holding fiat money in this environment is not a prerequisite for obtaining consumption goods. Commodities with intrinsic value can serve as means of payment, thereby solving the problem of the double-coincidence of wants.

The idea that the inflation tax disincentivizes money holding is a long-standing view in economics (Bailey, 1956). In microfounded models with flexible prices, the inflation tax typically reduces individuals' real balances and alters their intertemporal consumption-saving optimal condition. In our setup, prices are fixed. The inflation tax lowers people's real balances because the government randomly confiscates fiat money from money holders. This design, pioneered by Li (1995), captures the essence of seigniorage: the government earns revenue while people holding money incur a wealth loss. Although this characterization of an inflation tax departs from its more standard representation as an erosion of real balances through price increases, it has the advantage of making it clear in laboratory experiments that holding money is costly. The rich microeconomic interactions in our analysis allow us to distinguish three different and widely debated aspects of the inflation tax: (1) its cost for the individual; (2) its expansionary effects; (3) its distortionary effects on production and consumption. Another advantage of using the KW model for laboratory experiments is that it is easy for subjects to comprehend the details of the environment.

Laboratory experiments have tested some properties of the KW model with fiat money (Duffy and Ochs, 2002). However, the model's predictions about the effects of an inflation tax remain unverified. The predicted effects of the inflation tax and the actual lab outcomes are not obvious. This is because, on the one hand, the model gives rise to multiple equilibria, and on the other hand, the self-referential nature of money makes it difficult to anticipate how an inflation tax will alter people's trading choices.

The environment comprises three reproducible and durable goods, along with a non-reproducible object serving as fiat money. Trade occurs in a decentralized setting through random, anonymous pairwise matching. We parameterize the model in terms of consumption utility, production cost, and inventory costs, enabling speculative and fundamental equilibria with complete or partial acceptance of fiat money to emerge by varying the quantity of money or by introducing an inflation tax. The model implies that in a region with a low to medium stock of money and no inflation tax, individuals coordinate on a speculative equilibrium with full acceptance of fiat money. Alternatively, when the stock of money is large, the economy operates in the fundamental equilibrium because the high-storage cost commodity loses marketability relative to the low-storage cost commodity. In this high-stock money region, however, complete acceptability of fiat money still holds. A mild inflation tax is more consequential: holders of the low-cost storage good do not accept fiat money. Not only does the low-cost commodity gain liquidity value relative to fiat money, but also relative to the high-storage cost good. Consequently, the economy ends up in a fundamental equilibrium.

We verify the model economy's predictions through laboratory experiments. Since the outcomes of strategic interactions among a very large number of agents can differ from those among a small number of individuals, we adapted the baseline model to an economy with a finite number of agents. We then used this adapted model to simulate exchanges among computer agents, ensuring the same number of participants and payoffs as in the laboratory experiments.

The paper is organized as follows: The next section reviews the relevant literature. Section 3 briefly presents the extended KW model, characterizes the steady-state Nash equilibria, and discusses the welfare consequences of introducing an inflation tax or changing the quantity of fiat money. This section also outlines four key implications to test in laboratory experiments. Section 4 introduces a similar KW model adapted to a finite number of agents. Section 5 describes the setup of laboratory experiments, summarizes the main outcomes, including welfare results, and relates them to the literature. Section 6 analyzes the laboratory data to test four implications of the model regarding the acceptance of money and the distortionary production effects of the inflation tax. Section 7 discusses the robustness of the statistical analysis. Section 8 concludes.

2. Literature review

There has been a growing body of literature that examines monetary issues in experimental settings. One strand of this literature has analyzed the role of money as a medium of exchange (Duffy and Ochs, 1999, 2002, Camera et al., 2003; Camera and Casari, 2014; Duffy and Puzzello, 2014; Jiang and Zhang, 2018; Rietz, 2019; Ding and Puzzello, 2020). More recent literature has explored how key equilibrium predictions of search models are affected by monetary policy (Duffy and Puzzello, 2022; Jiang et al., 2023).

Duffy (2016) and Hommes (2021) have written excellent surveys of papers on the adaptation of search models to test monetary experiment predictions in laboratory settings. Therefore, we briefly discuss a selected number of papers to clarify the contribution of this work and how our approach relates to the existing literature. Traditionally, inflation tax has been viewed as a tax on real money balances leading to a dead wight loss, like an excise tax of a commodity (Bailey, 1956 and Friedman, 1969). Lucas (1987), Cooley and Hansen (1989) calculated within a general equilibrium setting compensated measures of the costs of inflation – i.e. the consumption that an individual would require to be as well off as under zero inflation. These earlier works were based on cash-in-advance models: the acceptance of money was not for its liquidity value but either because it was exogenously imposed as a precondition for trade or because it was included as an argument in the utility function. Such ways of capturing the role of money in macroeconomic models are problematic. Lucas suggested that "[t]heories that take us farther on the search for foundations, such as the matching models introduced by Kiyotaki and Wright (1989), are needed" (Lucas, 2000, p. 272). We follow this line of investigation by adapting the Kiyotaki and Wright (1989) model to an environment with an inflation tax, according to the design of Li (1995), who introduced the tax as a random confiscation of money holdings. Li (1995) showed that the inflation tax can have beneficial productivity and welfare effects by spurring people to intensify their search efforts. In our work, the search effort is exogenous, yet the inflation tax affects the flow of production by conditioning the emergence of equilibria that differ in trade patterns. Unlike Li (1995), in our setup, the inflation tax tends to favor the emergence of equilibria with a lower flow of production. This result is related to the concept of the robustness of money. Kiyotaki and Wright (1991) showed that monetary equilibria exist even when money is a return-dominated asset. In our work, both in theory and in experiments, money circulates in the economy even when the inflation tax is above the cost of holding commodity money. The inflation tax, however, reduces the intensity of trade and production.

Earlier works by Duffy and Ochs (1999, 2002) and Duffy (2001) used a similar KW framework to explore, in laboratory experiments, the acceptance of money and the emergence of speculative equilibria. We extend this literature by considering the effects of the inflation tax on individual behavior. Recent laboratory experiments on the effects of the inflation tax have relied on New Monetarist models by Lagos and Wright (2005) and Rocheteau and Wright (2005). These experiments assess the distortionary effects of the inflation tax by examining changes in agents' production efforts resulting from the expected increase in prices. Jiang et al. (2023) compare three different mechanisms of monetary injections to generate inflation: proportional transfers, lump-sum transfers, and government purchases. They find that the proportional transfers mechanism is the least distortionary both in theory and in the laboratory. Our experiment more closely resembles their government spending experimental design. In contrast to Jiang et al. (2023), where the erosion of inflation occurs through an increase in prices, in our design, government agents randomly confiscate assets from money holders. From an experimental perspective, our setup is also similar to Duffy and Puzzello (2022), where the government confiscates money to generate deflation. Our paper is also related to Anbarci et al. (2015), who study inflation in a Lagos and Wright (2005) environment. Like our work, they examine the inflation tax without changing the money supply, and money holding is costly.

We capture the feature of the model economy in which individuals have an infinite horizon and discount future gains by designing the random block termination scheme proposed by Fréchette and Yuksel (2017). While random termination schemes are widely used in experimental economics, including in recent experiments on monetary policy (Duffy and Puzzello, 2022, and Jiang et al., 2023), they have been criticized on the grounds that the experimenter cannot credibly implement a game that lasts indefinitely. This can be particularly problematic in experiments with fiat money. In a finite-time game, rational agents would not accept fiat money in the last period, and by backward induction, they would reject it in earlier periods as well. While rewarding participants who hold fiat money at the game's end could ensure its acceptance in the laboratory, such a reward would create uncertainty about whether people accept fiat money for its payment role or its intrinsic value at the end of the game. To overcome this issue, Jiang et al. (2024) suggest using a finite-time model that still exhibits a monetary equilibrium. In our design, subjects do not receive payoffs for holding money at the end, and trade, production, and consumption are possible even without accepting fiat money. Nevertheless, we observe a clear tendency for money acceptance in no-inflation scenarios.

Our work broadly relates to the extensive experimental literature that relies on New Keynesian models, where sticky prices significantly amplify the real effects of money injections. While these models (see, among the most recent contributions, Assenza et al., 2021) generally find the inflation tax channel to be mute, in our work, individuals can and do react to seigniorage by reducing their willingness to accept money.

Finally, our interest in simulating the model with computer agents connects to the literature, spurred by Molico (2006), that uses numerical methods to characterize equilibria in a search-theoretic model of monetary exchange.

3. The model

The model economy is similar to that of KW, with the addition of an inflation tax. The time is divided into discrete periods. The economy is inhabited by infinitely-lived agents of mass one. There are three types of individuals and three types of goods, both denoted by $i = 1,2,3$. The population is equally divided among the three types. A type i individual consumes only goods of type i, and is specialized in producing goods of type $i+1$ (modulo 3). Production takes place immediately after consumption. Each unit of consumption produces a utility of U, while the cost of producing each unit is D. The sequence of consumption and production then yields a net utility of $u = U - D$. Goods are indivisible and durable. A unit of type i good can be stored at a cost of c_i per period. In addition to commodities, agents can also hold fiat money, m, at no cost. Money serves as a means of transaction but does not bring any utility in itself. An individual can hold either one unit of a type i good or one unit of money, but not both. This simplifies the analysis and makes the decision to accept money more transparent. The fraction of the population holding money is equal to the overall stock of money, Q.[1] A common discount factor of $0 < 1 - \rho < 1$ is applied between each period, but not within a period. At the start of each period, the government collects a tax from money holders. Because in this set up prices are fixed, Li (1994, 1995) first proposed to introduce inflation tax as a random confiscation of fiat money. Following this insight we assume that a money holder pays a tax of one unit with a probability of δ_m and then immediately produces one unit of commodity at a cost D. Afterwards, agents pay storage costs if they are holding commodities. Then, agents are randomly and uniformly paired for bilateral trade. Two parties engage in trade if and only if they both agree to the exchange. A type i always accepts good i and consumes it immediately. Therefore, a type i trader arrives at the trade meeting with either with good $i+1$, or good $i+2$, or m. The choice of type i individuals to trade good j for good k is denoted with $s^i_{j,k} = 1$; otherwise $s^i_{j,k} = 0$. The government uses the collected tax revenue, $\delta_m Q$, to purchase goods, on a one-to-one basis, from agents holding commodities who are selected at random with probability δ_g. We assume that government runs a balanced budget, that is $\delta_m Q = \delta_g (1 - Q)$. This results in a quantity of money, Q, that remains constant over time and in $\delta_g = \delta_m Q/(1 - Q)$.

[1] There is a significant body of work dealing with asset-holding restrictions, such as those described here (e.g., Cavalcanti and Wallace, 1999; Duffie et al., 2005).

3.1. Commodities, fiat money, and trading strategies

This section briefly describes the evolution of the stock of commodities and money and the optimizing trading strategies.

Distribution of Commodities and Fiat Money. We denote with $p_{i,j}(t)$ the proportion of type i agents that hold good j at time t. Since $p_{i,i}(t) = 0$, we have that

$$p_{i,i+1}(t) + p_{i,i+2}(t) + p_{i,m}(t) = \frac{1}{3}. \tag{1}$$

The following equation accounts for the overall holding of fiat money:

$$p_{1,m}(t) + p_{2,m}(t) + p_{3,m}(t) = Q. \tag{2}$$

The state of the economy at time t can then be represented by the five-dimensional vector $\mathbf{p}(t) = (p_{1,2}(t), p_{2,3}(t), p_{3,1}(t), p_{1,m}(t), p_{2,m}(t))$. The Online Appendix A.1 details the evolution of $\mathbf{p}$, for a given set of strategies $s^i_{j,k}$ and an initial state $\mathbf{p}(0)$. The property of the dynamics of a similar environment are also studied in Iacopetta (2019) and Bonetto and Iacopetta (2019). We say that $\hat{\mathbf{p}}$ is a steady state for the strategies $s^i_{j,k}$ if $\mathbf{p}(t) = \hat{\mathbf{p}}$ for every t.

Strategies. Individuals are aware of the state of the economy, denoted by $\mathbf{p}$, and consider the strategies of all other individuals, including those of their own type, as fixed. The expected discounted utility of a type i agent a time t, playing strategy $\sigma^i_{j,k}$ is:

$$V_{i,j}(t) = \sum_{\tau=t}^{\infty}(1-\rho)^{(\tau-t)} \sum_{l} \pi^i_{l,j}(\tau,t) v_{i,l}(\mathbf{p}(\tau)), \tag{3}$$

where $\pi^i_{l,j}(\tau,t)$ is the probability that the individual will hold good l at time $\tau \ge t$, given that he carries good j at time t and plays strategy $\sigma^i_{j,k}$. The term $v_{i,l}(\mathbf{p})$ is the flow of utility, net of storage costs, associated to the distribution of holdings $\mathbf{p}$. Note that both $\pi^i_{l,j}(\tau,t)$ and $v_{i,l}(\mathbf{p})$ are dependent on the strategies of all other individuals. In a steady state, the value functions, $V_{i,j}$, are linked to the inventory distribution, $\mathbf{p}$, through a system of linear equations. Given the strategies of the rest of the population, $\sigma^i_{j,k}$ maximizes the expected flow of utility of a type i if and only if

$$\sigma^i_{j,k} = \begin{cases} 1 & \text{if } \Delta^i_{j,k} < 0 \\ 0 & \text{if } \Delta^i_{j,k} > 0 \\ 0.5 & \text{if } \Delta^i_{j,k} = 0, \end{cases} \tag{4}$$

where $\Delta^i_{j,k} \equiv V_{i,j} - V_{i,k}$. Eq. (4) implies that $\sigma^i_{j,k} = 1 - \sigma^i_{k,j}$ and $\sigma^i_{j,j} = 0$. Thus, the full set of strategies for a type i agent simplifies to $\boldsymbol{\sigma}^i = (\sigma^i_{i+1,m}, \sigma^i_{i+2,m}, \sigma^i_{i+1,i+2})$, where $\boldsymbol{\sigma}^i \in \Sigma = \{(1,1,1),(1,0,1),(1,1,0),(0,1,0),(0,0,1),(0,0,0)\}$.[2] The 3×3 matrix $\boldsymbol{\sigma} = (\boldsymbol{\sigma}^1, \boldsymbol{\sigma}^2, \boldsymbol{\sigma}^3) \in \Sigma^3$ summarizes all the strategies of the three types of agents.

3.2. Nash equilibrium

A steady state Nash equilibrium is a time-invariant set of strategies that maximizes individuals' payoffs. Denote the set of strategies for the population with $\mathbf{s} = (\mathbf{s}^1, \mathbf{s}^2, \mathbf{s}^3) \in \Sigma^3$, where $\mathbf{s}^i = (s^i_{i+1,m}, s^i_{i+2,m}, s^i_{i+1,i+2}) \in \Sigma$, and the best responses of the three types of individuals with $\boldsymbol{\sigma} = (\boldsymbol{\sigma}^1, \boldsymbol{\sigma}^2, \boldsymbol{\sigma}^3) \in \Sigma^3$ where $\boldsymbol{\sigma} = \boldsymbol{\mathcal{B}}(\mathbf{s})$. The set of strategies $\mathbf{s}^*$ is a Nash equilibrium if $\boldsymbol{\sigma} = \mathbf{s}^* = \boldsymbol{\mathcal{B}}(\mathbf{s}^*)$.

Familiar properties of KW Nash equilibria are easy to verify when there is no fiat money in the economy, that is when $Q = 0$. For instance, if $c_1 < c_2 < c_3$, two equilibria exist: a *fundamental* equilibrium characterized by the strategy triplet $(s^1_{2,3}, s^2_{3,1}, s^3_{1,2}) = (0,1,0)$, and a *speculative* equilibrium, where the triplet is $(1,1,0)$. Only the strategies of type 1 individuals differ in the two equilibria. The fundamental equilibrium occurs when $(c_3\text{-}c_2)/u > 1/6$; otherwise, the speculative equilibrium arises. In the latter, type 1 agents trade good 2 (with low storage cost) for good 3 (with high storage cost) due to liquidity considerations; good 3 is more likely than good 2 to be accepted in future trades for good 1.

When the supply of money is positive, $Q > 0$, these two equilibria can be associated with full or partial acceptance of money. For instance, the matrix

$$\mathbf{s} = \begin{pmatrix} s^1_{2,m} & s^2_{3,m} & s^3_{1,m} \\ s^1_{3,m} & s^2_{1,m} & s^3_{2,m} \\ s^1_{2,3} & s^2_{1,3} & s^3_{1,2} \end{pmatrix} = \begin{pmatrix} 1 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{pmatrix}$$

depicts a speculative equilibrium (see the last row of the matrix) where fiat money is generally accepted, except for type 2 individuals who possess good 1 (indicated by the 0 in the middle row). This scenario may arise when inflation is high. In this case, type 2

[2] An agent of type i has eight possible trading choices. However, the use of a simple transitivity trading rule, such as, if $\sigma^1_{2,3} = 0$ and $\sigma^1_{2,m} = 1$, then $\sigma^1_{3,m} = 1$, narrows down their choices to the six options within Σ.

Table 1
Parameters.

Disc. Rate	Utility			Storage costs		
ρ	U	D	u	c_1	c_2	c_3
0.1	130	30	100	4	10	20

individuals prefer to pay the storage costs of holding good 1 rather than holding onto fiat money, so as to avoid paying the inflation tax.

3.3. Implications and hypotheses

Fig. 1a provides an overview of the steady-state equilibria that emerge over a range of fiat money $Q \in [0, 0.8]$ and an inflation tax rate $\delta_m \in [0, 0.1]$ under our preferred set of parameter values reported in Table 1. We chose these parameter values with the objective of generating speculative equilibria with full or partial acceptability of money and fundamental equilibria with full or partial acceptability of fiat money at a moderate level of seigniorage. Additionally, we aimed for a set of parameter values that are easy to explain to lab participants and simple to remember during the game.

We started with a consumption utility $U = 130$ and a production cost $D = 30$, resulting in a net utility associated with consumption $u = 100$, a convenient number to relate to production and storage costs. One important question of our investigation is the emergence of speculative equilibrium, where type 1 agents trade good 2 for good 3. To mark a significant difference in the storage costs of these two goods, we set $c_2 = 10$ and $c_3 = 20$. Accepting to swap a good with another that is twice as expensive to carry supports the notion that liquidity is relevant in trade choices. Our choice of the storage cost for good 1, $c_1 = 4$, addresses another central question: the robustness of fiat money. Recall that this model admits both monetary and non-monetary equilibria. In a non-monetary equilibrium, commodities can still serve as means of payment, with good 1 being the best positioned due to its low storage cost. We then pick a c_1 sufficiently above zero to increase the likelihood that money is largely accepted in laboratory experiments in the absence of seigniorage, but sufficiently low that some participants refuse it in the presence of moderate seigniorage. The relatively high production cost D is another element to ensure participants understand that money holding incurs a significant carrying cost—in our setup, money confiscation is followed by production. Fig. 1a shows equilibria with partial acceptability of money in which type 2 agents do not sell good 1 for fiat money. Additional equilibria in which type 3 agents do not sell good 1 for fiat money also exist.[3]

Fig. 1a shows that with no inflation tax an increase in the stock of money reduces the incentives for type 1 agents to play speculative strategies, or, equivalently, favors the emergence of a fundamental equilibrium. To understand why, it is useful to recall that a speculative equilibrium can be sustained if type 3 agents holding good 1 are sufficiently numerous relative to type 2 agents holding good 1. In other words, the liquidity advantage of the high-storage cost good is sufficiently large to justify facing the extra storage cost. Given the unit inventory constraint of our set up, an increase in the stock of money reduces on a one to one basis the holding of commodities. For type 3 agents, such replacement always involves good 1, as they never hold good 2 in any of the two equilibria under consideration. For type 2 agents, a greater quantity of money in the inventory implies a reduction not only of good 1 but also of good 3. Thus, a greater quantity of money tends to reduce type 3's holding of good 1 more rapidly than type 2's holding of good 1.

Fig. 2a illustrates these mechanisms from a different perspective: it plots $\Delta^1_{2,3}$, $\Delta^2_{m,1}$, and $\Delta^3_{m,1}$ against Q. From these plots, we learn that: (i) $\Delta^1_{2,3}$ turns from negative to positive over this range, implying that for sufficiently high Q, type 1 switches from a speculative to a fundamental strategy; (ii) for both type 2 and type 3, fiat money is worth more than good 1, that is $\Delta^2_{m,1}$ and $\Delta^3_{m,1}$ are both positive, and these differences decline with Q. Based on these predictions, we test two hypotheses in our laboratory experiments:

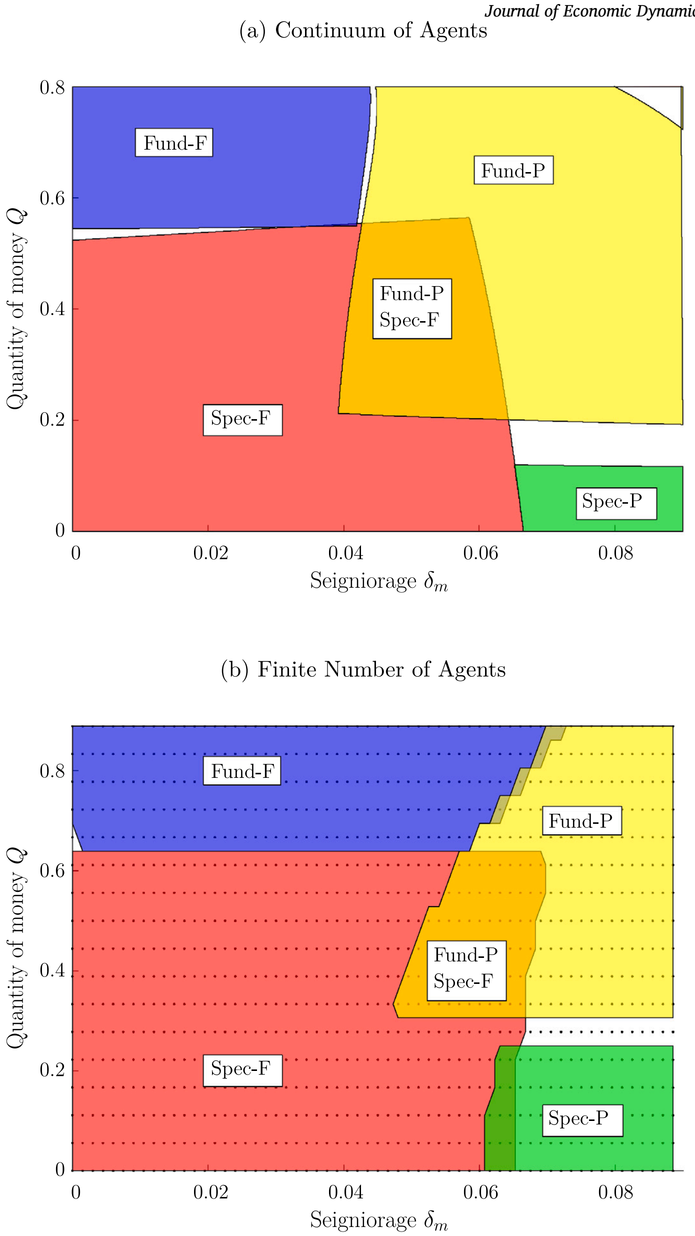
Hypothesis 1 (H1): The incentives for type 1 agents to play speculative strategies weaken with an increase in the quantity of fiat money.

Hypothesis 2 (H2): The evaluation of money decreases with the quantity of money.

Specifically, we set up three laboratory treatments that differ only in the quantity of money Q, with Q being low, medium, and high. We then verify whether type 1 individuals more frequently adopt fundamental strategies as Q increases across the three treatments. Similarly, we verify in the laboratory whether the acceptance of money by type 2 and type 3 weakens as Q rises.

Turning our attention to the effects of the inflation tax, Fig. 2b suggests that type 2 individuals do not accept fiat money for good 1 if the inflation rate is sufficiently high, and that type 1 agents may switch from speculative to fundamental strategies as inflation increases. Fig. 2b shows similar properties by illustrating the dependence of $\Delta^1_{2,3}$, $\Delta^2_{m,1}$, and $\Delta^3_{m,1}$ on the seigniorage rate, δ_m, when $Q = 1/3$. The value of money (relative to good 1) for type 2 and type 3 individuals, $\Delta^2_{m,1}$ and $\Delta^3_{m,1}$, decreases as δ_m increases. At

[3] Our set of parameters differs from those used in Duffy and Ochs (2002) because we are driven by different research questions. In our work, all equilibria emerge under the same parameter values for net utility and storage costs shown in Table 1. In contrast, in Duffy and Ochs (2002), the fundamental equilibrium (Case 1) is obtained under a different set of parameters for u and c_i than the speculative equilibrium (Case 2). Similar to their work, our parameters are not chosen with the intention of maximizing welfare for any specific money supply. Section 5.4 discusses the welfare differences between monetary and credit equilibria. The source code to generate the equilibria shown in Fig. 1 is available at https://bonetto.math.gatech.edu/KW/Sources.



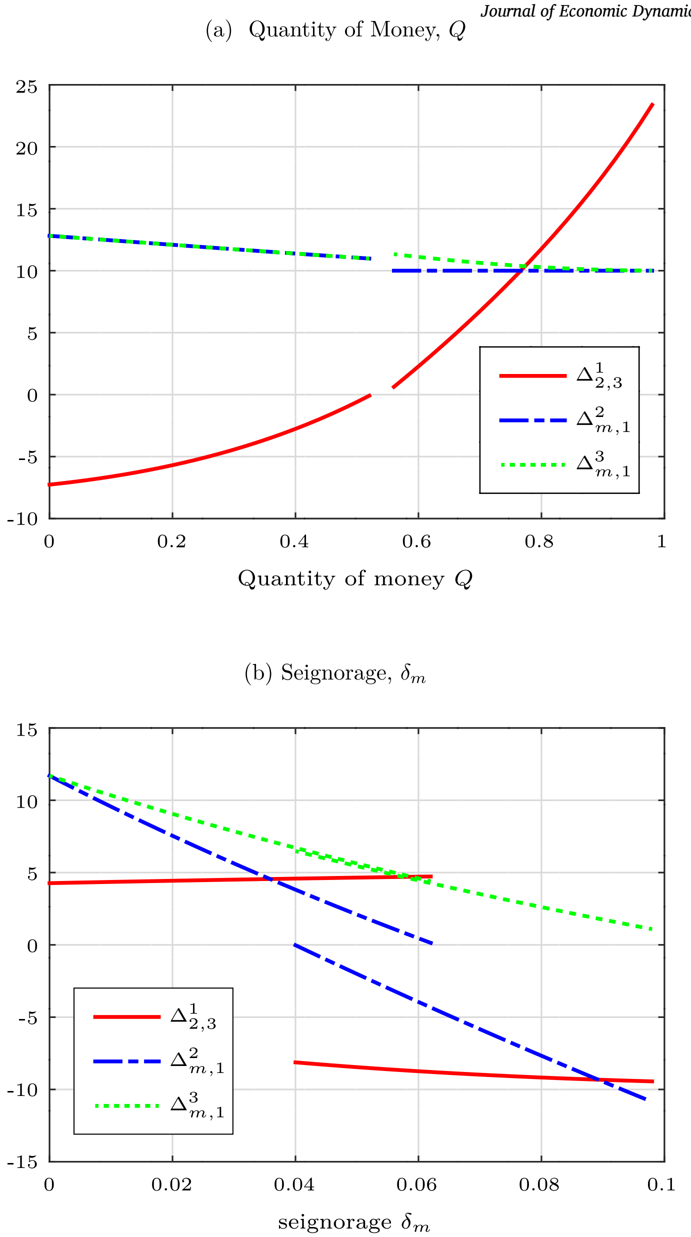
Notes. (1) Abbreviations: **Fund**amental; **Spec**ulative; **F**ull or **P**artial acceptance of money. (2) In panel (b) equilibria are computed on the dots via the method described in Online Appendix A; in panel (a) they are computed on a much thinner grid. See Table 1 for parameters.

Fig. 1. Steady State Equilibria.

intermediate levels of seigniorage rates, multiple equilibria exist. However, at the lower and higher extremes of the interval $[0, 0.09]$, the speculative and fundamental equilibria are unique. The increase in δ_m induces a shift in behavior from speculative to fundamental among type 1 individuals because the decline in the value of fiat money leads type 2 individuals to accumulate relatively more of good 1. Consequently, type 2's holdings of good 1 increase relative to those of type 3, making type 1's fundamental strategy more profitable than the speculative one.

The fact that type 2 agents prefer to hold good 1 rather than fiat money does not necessarily imply that type 1 agents will change their trading strategy. This shift does not occur when the initial stock of money is either low or high. When the stock of money is high, the economy is already in a fundamental equilibrium even without an inflation tax. The inflation tax can then only reinforce the conditions for the emergence of a fundamental equilibrium. When there is a low stock of money, the inflation tax only marginally alters the distribution of commodities, and thus the speculative equilibrium persists even with a moderate inflation tax.

These observations lead us to explore two additional and interrelated hypotheses in our laboratory experiments:



Notes: Two equilibria coexist when $\delta_m \in [0.041, 0.065]$ (see also Fig. 1a).

Fig. 2. Trade Strategies and Money Acceptance.

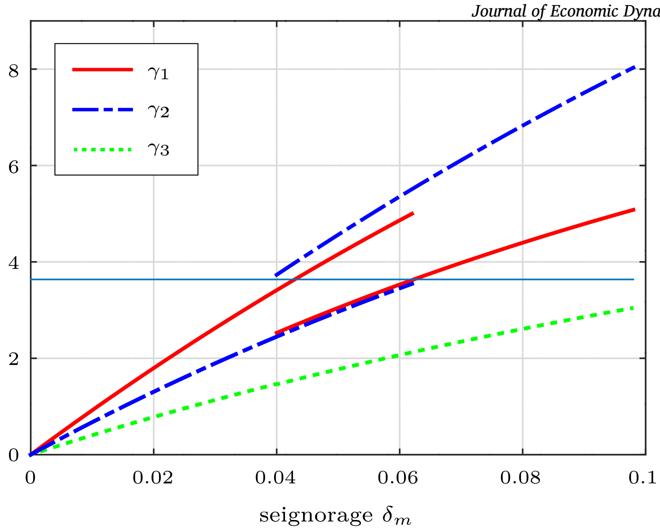
Hypothesis 3 (H3): Speculative behavior decreases with the inflation tax.

Hypothesis 4 (H4): The acceptability of money decreases with the inflation tax.

To test H3, we evaluate whether the frequency at which type 1 agents trade good 2 for good 3 is lower in treatments with the inflation tax than in treatments without the inflation tax for two levels of money, Q. Similarly, we test H4 by considering whether the frequency at which type 2 and type 3 agents trade good 1 for money decreases with the seigniorage rate.

3.4. *Inflation tax and welfare*

In this section, we explore three primary channels through which the inflation tax influences people's welfare: (i) the direct cost; (ii) the government's use of seigniorage; (iii) the distortion of production activities. Before proceeding, it is important to clarify that while these three types of inflation costs are studied across a broad class of monetary models, the monetary instruments and mechanisms generating inflation may differ significantly. In standard search models with divisible money, such as those by Lagos and Wright (2005) and Rocheteau and Wright (2005), the fraction of individuals holding money is endogenous, prices are flexible,



Notes. (1) The flat line represents is the one-period discounted storage cost $c_1 = 4$. (2) Two equilibria coexist when $\delta_m \in [0.041, 0.065]$ (see also Fig. 1a).

Fig. 3. Inflation Tax on Money Holders, γ_i.

and both respond to an exogenous money supply. The cost of inflation to individuals is represented by a loss in purchasing power for money holders and, potentially, by reduced production effort. In Section 5.4, we discuss three mechanisms for generating inflation in standard models with divisible money, as studied in Jiang et al. (2023). In the current setup, the monetary instrument involves the frequency of money confiscation and changes in the fraction of individuals holding money. However, we will show that the inflation tax rate is endogenous: while in the standard search model with divisible money, this depends on how money supply influences bargaining and production distortion, in our framework, it relies on the response of money distribution and capital losses associated with seigniorage. More specifically, here the direct burden of seigniorage for money holders has two components. First, a money holder of type i who gives her unit of fiat money to the government replaces it with her production good $i+1$, incurring an immediate utility cost of D. Second, the replacement of fiat money with the production good changes the asset position of the individual affected by the inflation tax. Type i incurs a capital loss of $V_{i,i+1} - V_{i,m}$ — or a capital gain if this difference is negative. Given that the probability of any money holder being subject to seigniorage is δ_m, the expected utility cost of seigniorage for the money holder is $\gamma_i = \delta_m[D + V_{i,i+1} - V_{i,m}]$. Observe that the capital loss $V_{i,i+1} - V_{i,m}$ and the cost of reproduction both occur in the same period, as an individual immediately replaces the confiscated unit of money with a production good. Therefore, the capital loss does not require discounting. Fig. 3 plots γ_i against the seigniorage rate δ_m. Fig. 3 plots γ_i against the seigniorage rate δ_m. Of particular interest is the behavior of γ_2 relative to the storage cost of good 1, due to its role in equilibrium selection. Denoting δ_m^* as the seignorage rate at which γ_2 equals the one-period discounted storage cost c_1 (discounted because it is paid at the beginning of the following period), Fig. 3 shows that when δ_m is below δ_m^* type 2 agents prefers fiat money to good 1, whereas when δ_m exceeds δ_m^*, they do not. Furthermore, type 2's change in money acceptance strategy also induces type 1 agents to switch from speculative to fundamental strategies. The inflation cost of γ_i for money holders differs across the three types due to the capital loss component $V_{i,i+1} - V_{i,m}$. Under fundamental strategies, the capital loss is greater for the type 2 individuals than for types 1 and 3, as type 2 individuals are penalized more heavily by the storage cost. To clarify, we consider six equilibria from the Fig. 1a. Table 2 provides an overview of the distribution of goods and commodities, $p_{i,j}$, across these six selected equilibria. In three equilibria, there is no seigniorage, and the supply of money, Q, ranges from low (2/18) to medium (6/18) to high (10/18); we refer to these equilibria as L_0, M_0, and H_0, respectively. The remaining three equilibria, labeled L_+, M_+, and H_+, exhibit the same variations in the supply of money but with an 8% seigniorage rate. With the parameter values in Table 1, we find that in M_+, γ_2 is 6.75, compared to 4.27 and 2.60 for γ_1 and γ_3, respectively (see Table 4a). A similar ranking holds in the H_+ scenario. However, when type 1 agents play speculative strategies, their capital loss is further increased by the difference $V_{1,3} - V_{1,2}$: indeed, in L_+, $\gamma_1 > \gamma_2 > \gamma_3$.

The inflation cost computed so far assumes that an individual currently holds money. Nevertheless, since any agent's position changes over time, it is also relevant to assess the average inflation cost for each type of individual. Following the standard in the literature, we express this as a fraction of consumption. We define the inflation tax rate for type i as $\tau_i = \gamma_i(p_{i,m}/\theta)/C_i$, where C_i represents the average consumption flow of type i, calculated as $C_i = \sum_k \sum_j p_{i,j} p_{k,i} s^k_{i,j}$, and $p_{i,m}/\theta$ accounts for the share of type i individuals holding money.

To facilitate comparisons with the experimental session results, we also calculate an inflation tax rate that includes only the reproduction cost D (thus excluding the capital loss), denoted as $\tau_D = \delta_m D \sum_{i=1}^{3} p_{i,m}/C_i$.

Unlike γ_i, τ_i also captures how the distribution of money in the economy weighs on the inflation cost of each type of individual. Specifically, because the fraction of type 3 individuals who hold money is larger than that of the other types, the frequency at which they are subject to inflation is also relatively higher. For instance, Table 2 reports that in M_+, $p_{3,m}$ is 0.16, whereas $p_{1,m}$ and $p_{2,m}$ are 0.1 and 0.07, respectively. Hence, the distribution of money $p_{i,m}$ tends to smooth out the differences in inflation across types. For

Table 2
Initial Distribution of Goods and Money, Continuum of Agents.

(δ_m, Q)	$p_{1,2}$	$p_{1,3}$	$p_{1,m}$	$p_{2,3}$	$p_{2,1}$	$p_{2,m}$	$p_{3,1}$	$p_{3,2}$	$p_{3,m}$	Equil. type
L_0	0.22	0.09	0.03	0.13	0.16	0.044	0.29	0.00	0.04	Spec-F
M_0	0.18	0.06	0.09	0.12	0.09	0.12	0.22	0.00	0.12	Spec-F
H_0	0.16	0.00	0.17	0.10	0.04	0.18	0.13	0.00	0.20	Fund-F
L_+	0.22	0.08	0.03	0.13	0.18	0.02	0.28	0.00	0.06	Spec-P
M_+	0.23	0.00	0.10	0.14	0.13	0.07	0.17	0.00	0.16	Fund-P
H_+	0.15	0.00	0.19	0.10	0.10	0.13	0.10	0.00	0.23	Fund-P

Note. The quantity of money, Q, is 2/18 (L), 6/18 (M), and 10/18 (H). The 0 and + subscripts of L, M, and H, mean $\delta_m = 0$ and $\delta_m = 0.08$, respectively.

Table 3
Welfare and Consumption (in utils) per Period, Continuum of Agents.

(δ_m, Q)	C_1	W_1	C_2	W_2	C_3	W_3	C	W	$\hat{W}$	Equil. type
L_0	28.34	100.98	28.34	120.28	28.34	182.98	28.34	134.75	134.75	Spec-F
M_0	23.14	87.31	23.14	96.98	23.14	151.53	23.14	111.94	111.94	Spec-F
H_0	14.17	60.50	14.17	38.59	14.17	93.65	14.17	64.25	64.25	Fund-F
L_+	28.08	98.28	28.08	114.14	27.95	177.72	28.04	130.04	141.60	Spec-P
M_+	18.59	65.54	17.94	35.67	17.68	103.64	18.07	68.28	102.95	Fund-P
H_+	12.74	41.31	13.13	19.23	13.13	71.52	13.00	44.02	101.79	Fund-P

Notes. (1) Welfare values are computed based on Table 2 and Table C.1. (2) Table 2 implies the following ratios of W_1, W_2, W_3, and W on M_+ relative to M_0: 0.75, 0.37, 0.68, and 0.61, respectively. The corresponding ratios of H_+ relative to H_0 are 0.68, 0.50, 0.76, and 0.69. (3) The description of the column (δ_m, Q) is in Table 1.

example the highest and lowest values of the inflation tax rate τ_i in M_+ are $\tau_2 = 0.079$ and $\tau_1 = 0.069$, which are less than one-fifth apart (Table 4b). Conversely, in M_+ the highest inflation cost for money holders, $\gamma_2 = 6.75$, is more than twice as large as the lowest value, $\gamma_3 = 2.60$ (Table 4a). Turning to the economy's average cost of inflation, under the parametrization of Table 1, we find that in L_+, $\tau_2 = 0.9\%$, $\tau_1 = \tau_3 = 1.7\%$, and $\tau = 1.5\%$ (4). Increasing the quantity of money results in higher inflation tax rates: for instance, moving from L_+ to H_+, τ increases from 1.5% to 15.1%. Conveniently, because in our setup consumption is equal to output, τ also represents the inflation tax rate relative to output.[4]

The incidence of inflation estimated so far is mitigated by the fact that the government uses the tax revenue to purchase goods from randomly selected commodity holders. These earn a surplus by selling their commodities to the government, at least to the extent that fiat money is worth more than their holdings. For instance, a type 1 holder of good 2 expects a capital gain $\delta_g(V_{1,m} - V_{1,2})$, and the average surplus of a type 1 holder in a given equilibrium is $g_1 = \delta_g[p_{1,2}(V_{1,m} - V_{1,2}) + p_{1,3}(V_{1,m} - V_{1,3})]/C_i$. Similar expressions can be derived for the other two types of agents, and for the economy's average, g. This is about one-third of τ. Interestingly, we find that g roughly corresponds to the capital loss component in τ, that is τ_D is approximately equal to the sum of τ and g (see Table 4b). We will appeal to this property in section 5.3 to estimate the inflation tax in the laboratory.

An important concern about the inflation tax is that it can distort production or investment decisions, potentially driving the economy to a relatively less efficient equilibrium. In New Monetarist models where the inflation tax operates on the intensive side, people may reduce their production effort today, anticipating that the inflation tax will reduce real balances and hence reduce tomorrow's consumption. In our framework with fixed prices, the distortion of real activities becomes manifest through a change in the frequency of trade. In some cases, the distortion is minimal. The fact that type 2 does not trade good 1 for fiat money in L_+ or H_+, for instance, reduces the per-period consumption relative to the equilibria L_0 and H_0 by only about one percent.[5]

When inflation causes type 1 to switch from speculative to fundamental strategies, however, the distortion is more significant. Such a switch occurs, most notably, when moving from the M_0 to the M_+ equilibrium. Aggregate consumption (and thus aggregate production) drops by approximately 22% (C goes down, in utility terms from 23.14 to 18.07; see Table 3). In other words, the inflation tax, by altering the trading strategies of type 1, creates negative externalities in trade, an outcome that contrasts with Li (1995), where inflation accelerates the intensity of search and hence trade. Thus, the distortionary production effect of the inflation tax is significant only when it drives the economy from a speculative to a fundamental equilibrium.

[4] Although bringing the model to macroeconomic data is beyond the scope of this analysis, it is worth noting that in the three equilibria, the money-to-output ratio exceeds that observed in advanced economies. For instance, the M1-to-GDP ratio in the USA in recent decades has ranged between 0.15 and 0.2 (see https://fred.stlouisfed.org/graph/?g=dQQ). In our L_+ equilibrium, the supply of money relative to output is approximately 40%. Aligning the model with the estimated money-to-output ratio could be achieved by increasing the intensity of search, which is normalized to one for simplicity here.

[5] According to Lucas (2000), who used a version of the Sidrauski model, the average household's welfare cost of inflation is modest. The cost is measured by the missed gain of holding an interest-bearing asset, as there are no benefits derived from money's role as a means of payment. As he puts it, "it is in everyone's private interest to try to get someone else to hold non-interest-bearing cash and reserves" (Lucas, 2000, p. 247). Lucas's estimates indicate that a one percent increase in the nominal interest rate, attributed to inflation, would result in a welfare reduction of around 0.012 percent of GDP for representative households in the steady-state equilibrium. Later studies, including Kurlat (2019), argued inflation costs could reach almost 0.1 percent of GDP when considering banks' operating costs.

Table 4
Inflation Tax and Gains from Money Injections, Continuum of Agents.

Panel A

(δ_m, Q)	γ_1	γ_2	γ_3	Equil. type
L_+	5.21	4.40	2.65	Spec-P
M_+	4.27	6.75	2.60	Fund-P
H_+	3.29	5.77	2.52	Fund-P

Panel B

(δ_m, Q)	τ_1	g_1	τ_2	g_2	τ_3	g_3	τ	τ_D	g	Equil. type
L_+	0.017	0.011	0.009	0.003	0.017	0.001	0.015	0.010	0.005	Spec-P
M_+	0.069	0.035	0.079	0.043	0.071	0.003	0.072	0.044	0.027	Fund-P
H_+	0.147	0.038	0.171	0.078	0.132	0.003	0.151	0.102	0.039	Fund-P

Notes. (1) The laboratory experiments yield an estimate for τ_D in the treatments M_+ and H_+ of 0.043 and 0.116, respectively. (2) The description of the column (δ_m, Q) is in Table 1.

The overall welfare consequence of the inflation tax for a type i agent can be estimated through the following welfare function for a type i agent:

$$W_i = \frac{p_{i,i+1}V_{i,i+1} + p_{i,i+2}V_{i,i+2} + p_{i,m}V_{i,m}}{\theta_i}.$$

Therefore, the aggregate welfare is

$$W = \sum_{i=1}^{3} \theta_i W_i.$$

Table 3 summarizes the levels of welfare, W_i and W, in our 6 selected equilibria. In line with the above observations, the average welfare, W, moves only marginally, around 3%, when going from L_0 to L_+. The welfare decline, however, is significantly larger when going from M_0 to M_+, and H_0 to H_+. Changes in welfare associated with inflation depend on the specific position of individuals with respect to consumption, trade, and production (a similar point is made, among others, in works by Albanesi (2007), Doepke and Schneider (2006), Coibion et al. (2017), and Chiu and Molico (2010)).

Following the above methodology, we differentiate the effects of inflation on the three types of agents across three aspects: the cost of the inflation tax, τ_i; the gains from money reinjection, g_i; and production distortion. According to Table 4b, there is very little variation in τ_i across the three types in any of the three equilibria L_0, M_0, and H_0. This follows from the fact that both the proportion of money holders and the flow of consumption, C_i, are similar across the three types in the three equilibria. In contrast, the capital gains from government purchases are unequally distributed: Type 3 agents gain the least as they value good 1 only slightly above fiat money; type 1 and type 2 agents profit significantly more from deals with the government than type 3 agents because they sell goods that on average have a higher cost of storage. Production distortion represents the largest potential source of inequality in this environment. This feature emerges clearly when comparing the changes in welfare, W_i, moving from M_0 to M_+ and from H_0 to H_+. The model predicts type 1 agents play fundamental in both H_0 and H_+; therefore, the difference in production is relatively small. The ratios of W_1, W_2, W_3, and W in H_+ relative to H_0 are 0.68, 0.50, 0.76, and 0.69, respectively. The corresponding ratios when comparing the equilibria M_+ and M_0 are 0.75, 0.37, 0.68, and 0.61. The much larger drop in W_2 relative to the average is due to the fact that type 2 agents are more penalized by type 1 agents not trading 2 for 3 in M_+.

The general takeaway point is that the inflation tax is more likely to generate welfare inequality when it alters trade patterns. Anticipating a result from the laboratory experiments, we find that the welfare changes in W_i caused by inflation are very close to those predicted by the model when moving from H_0 to H_+ but diverge significantly from the model's prediction when moving from M_0 to M_+.

The welfare losses determined so far did not consider the utility that the government can generate with effective use of the spending. One simple way to account for the government's utility is to assume that one unit of any commodity acquired by the government yields a utility of U. The welfare change due to seigniorage under this more comprehensive measure of utility is ambiguous: it declines moving from M_0 to M_+, but it increases moving from L_0 to L_+ or from H_0 to H_+ (see Table 3)

4. Small number of agents

Up to this point, we have derived Nash equilibria in an economy with a continuum of agents. However, as noted by Judd (1985), Feldman and Gilles (1985), and Khan et al. (2020), the properties of equilibria in such an environment may not necessarily hold in situations with a finite number of agents. To address this concern, we extended the analysis of the baseline economy to one populated with 18 agents, matching the number of subjects in our laboratory experiments. The Online Appendix, Section A.2, explains how we adapted the processes of matching, exchange, and confiscation from an economy with a continuum of agents to one with a finite number of agents. It also details the methodology we developed to estimate the individual value functions and to compute the Nash-like equilibria for the 18-agents economy.

We use this framework to address the question of whether, under the parameters reported in Table 1, the payoffs and the distribution of goods and money implied by the equilibria shown in Fig. 1a (continuum of agents) are consistent with those in an economy populated by 18 agents. We compute Nash-like equilibria for the 18-agent economy using the parameters from Table 1 and the same parameter space (δ_m, Q) as Fig. 1a. [6] The results displayed in Fig. 1b reveal a similar partition of the (δ_m, Q) space compared to the continuum-agent economy. [7] We will use the model with a finite number of agents in Section 5.4 to discuss predictions regarding the welfare effects of the inflation tax.

5. Laboratory experiments

5.1. Experimental design

We conducted 15 sessions of human subject experiments to test hypotheses derived from our model. Each session involved five treatments, each with the same parameters for consumption utility, production cost, and cost of holding goods, as shown in Table 1.

The treatments varied by the quantity of fiat money (Q) and inflation tax (δ_m). In treatments L_0, M_0, and H_0, δ_m was set to 0, and the fraction of the population storing good m was 2/18, 6/18, and 10/18, respectively. In the other two treatments, M_+ and H_+, δ_m was set to 0.08 and Q was 6/18 and 10/18, respectively. Because of space and budget limitations we had to restrict the experiments to 5 treatments. Relative to the quantitative illustrations of Sections 2 and 3, we dropped the case low stock of money with inflation, L_+, under the presumption that inflation is more likely to affect individuals' behavior in treatments with higher stocks of money.

While the outcome of each treatment can, in principle, be compared with that of any of the other four, we aim to study the effects of money supply and inflation separately. Therefore, to explore the effects of money supply, we compare the outcomes across the three treatments with no seigniorage: L_0, M_0, and H_0. To understand the effects of the inflation tax, we compare the outcome of the treatment M_0 with that of M_+ and the outcome of the treatment H_0 with that of H_+.

We performed the 15 sessions at the Experimental Economics Laboratory of the Institute of Social and Economic Research (ISER) at Osaka University between January and July 2020. Ten sessions took place in January and February 2020, and five sessions took place in July 2020. The laboratory closed due to COVID-19 for several weeks after February 2020. We recruited a group of 18 subjects for each session, with a total of 270 subjects recruited online through the ORSEE system. Out of these subjects, 77 were female, and their average age was 22 as they were students from Osaka University. Each subject participated in five games, each associated with one of the five treatments described above. Although we recruited participants for two-hour sessions, due to the random termination rule, sessions lasted an average of 100 minutes, including instruction and quiz time. No subject participated in more than one session, and none had prior experience with the type of games played in the laboratory.

The Online Appendix B provides an English translation of the written instructions given to participants at the beginning of each session. We also played a pre-recorded audio file of the written instructions to reinforce the content. The instructions informed participants that their type may change from one game to the next but would remain the same throughout each game. They also detailed the rules of the experiment, the objectives of each player type, and how to earn and lose points based on the values reported in Table 1. Participants learned that acquiring the consumption good would give them 130 points, that production would cost 30 points, and that carrying a commodity would depend on his or her type, according to Table 1. The instructions also explained that holding a "token", which was the name we used for fiat money, would cost no points but could be confiscated if displayed on their screen. Participants were informed that nobody could immediately earn points by acquiring a token as it cannot be consumed.

After answering any questions about the rules of the game, participants took a comprehension quiz to assess their understanding of the experimental instructions. The quiz asked participants to answer the same question until they selected the correct answer. Participants then learned about the computer interface.

For this experiment, including the comprehension quiz, we used the z-Tree computer program (Fischbacher, 2007). The program randomly matches participants, informs them of relevant information about their trading decisions, keeps track of historical information such as goods in storage, trading decisions, and accumulated points, and calculates summary statistics to give insight into the historical distribution of strategies.

Each game consists of one or more sets of ten trading rounds. The interval during which a trading round takes place is referred to as a period. At the start of each period, the computer program randomly matches all participants into pairs. Participants can then see on their computer screen information about the good held by their paired counterpart (refer to Fig. B.2 in the Online Appendix B). The player's screen also displays information about the player's own type, the type of good in storage, the cost of holding any of the three types of commodities, and the probability of fiat money confiscation. In addition, the screen reminds players about the payoffs, including a gain of 130 points for acquiring their consumption goods, a deduction for the storage cost based on the good being stored, and a cost of 30 points due to the production of a new good. Each player starts the first round with an endowment of 150 points to prevent the cumulative points from turning negative during the game. Throughout the game, players accumulate points that eventually are converted into cash. The end of this section describes in further details this conversion.

[6] We obtained the numerical results using Octave and C codes. A graphical interface, together with source codes and scripts, is available at https://bonetto.math.gatech.edu/KW.

[7] The relatively small gap between the partitions in Fig. 1a and Fig. 1b implies, however, that H_0 is characterized by fundamental strategies in the continuum-agent economy but by speculative strategies in the small economy. For simplicity, we will use the equilibrium strategies of the continuum-agent economy as a benchmark when discussing the outcomes of the laboratory experiments.

Table 5
Initial Distribution of Goods and Money: Computer and Laboratory Experiments.

Treatment	$n_{1,2}$	$n_{1,3}$	$n_{1,m}$	$n_{2,3}$	$n_{2,1}$	$n_{2,m}$	$n_{3,1}$	$n_{3,2}$	$n_{3,m}$
L_0	4	2	0	3	2	1	5	0	1
M_0	3	1	2	2	2	2	4	0	2
H_0	3	0	3	1	2	3	2	0	4
M_+	4	0	2	2	3	1	3	0	3
H_+	3	0	3	1	2	3	2	0	4

Notes. (1) Derived as an approximation of Table 2. (2) The description of the column (δ_m, Q) is in Table 1.

Each game is associated with one of five treatments, and the order in which the treatments are applied is different from session to session. The treatments are organized so that over the course of 15 sessions, each treatment takes up one of five possible positions three times. Each player starts the first round of the game with one unit of commodity or one token. Following a similar approach to that used in our numerical exercise with an 18-agent economy, the software randomly chooses the type of good or token for each player to reproduce the distribution of commodities and fiat money associated with a particular treatment (see Table 5). When two players are paired, they are asked if they want to trade the goods in their inventories. Players can only respond with Yes or No. They cannot trade again within the same period. If both players agree to trade, the goods are exchanged on a one-to-one basis. Before making a decision, a player can view the following information on the screen:

a) the probability of token confiscation
b) the probability that the game will end at the end of the period, if it was still running up to that point.
c) the number of agents of type i holding good j. By selecting the "History" tag player could also switch from the current distribution of holdings to the historical averages, counting from the beginning of the game. A "Current" tag would bring the screen back to the current distribution.

After the player makes a trade decision (Yes or No), a new screen appears (see Fig. B.3), displaying the player's holding and points, as well as the governmnent's confiscation of tokens (if any) during the current period. At the end of each 10-round block, the screen shows whether the game will continue for another 10 periods.

Following a common practice in this class of experiments, the game is randomly terminated, an approach that is meant to approximate an environment where individuals have an infinite horizon and apply a discount on future gains (Fréchette and Yuksel, 2017).[8] The game has a constant probability of ending (0.1) in any period, determined by a random number generated by the computer. Specifically, following the completion of a trading round, the computer picks a number from a uniform distribution over $[0, 1]$. If this number is between 0 and 0.1 the current trading round is the last one of the game considered for the calculation of the players' payoffs. Nevertheless, the game continues until the 10th period, at the end of which players learn that the game is over. The information delay allows for an increase in the number of observations (see Fréchette and Yuksel (2017) for a discussion). There is no restriction on the number of 10-period blocks that can be played in a single game, with the longest games lasting 40 periods.

While we recruited subjects for sessions of 120 minutes we did not tell them in advance how many games they would play. Of the 75 total games (5 per 15 sessions), 42 were over at the 10th period, 22 at the 20th, 7 at the 30th, and 4 at the 40th period. The distribution of periods across sessions is: 50 (1), 60 (1), 70 (6), 80 (1), 90 (1), 100 (3), 110 (1), 120 (1), where the figures in parenthesis indicate the number of sessions. Finally, to decide the reward, once the last game of the session has been played, we asked the computer program to choose one game at random among all the five played in that session. The basis for the cash payment was the cumulative points recorded by each player at the end of the randomly selected game. The initial endowment of 150 points was set high enough to ensure that, despite storage costs, the cumulative points for any randomly selected game and player remained positive. We converted one point into 10 JPY. Each participant received an additional reward of 500 JPY. We communicated the reward scheme at the beginning of each session, along with the other instructions about the rules of the experiment. A participant earned an average of 2910 JPY (approximately $27). In a testing phase of the experimental setup we verified that the differences in payoffs associated to alternative trading actions were sufficiently large to trigger behavioral responses across different treatments.

5.2. Experimental results

This section presents an overview of the results of our experimental sessions. It focuses on the trading behavior of players. Section 5 studies the data through statistical analysis. Table 6 reports the frequencies at which the three types of individuals were willing to trade away the good in their holdings for a different good or for fiat money, when such a circumstance materialized. These frequencies are obtained by studying 11 070 matches, observed over the 15 sessions.

Consumption Good. In line with the model's assumption that individuals acquire their consumption goods whenever such opportunities arise, individuals tended to trade their goods or fiat money for their consumption goods. For example, type 1 offered fiat

[8] In literature review Section 2 we summarize the recent debate about the assumption that the experimenter implements a game that lasts an arbitrarily long time.

Table 6
Frequencies of Offers in Laboratory Experiments.

	Panel I Type 1 Offers			Panel II Type 2 Offers			Panel III. Type 3 Offers		
	Money for			Money for			Money for		
(δ_m, Q)	1	2	3	2	3	1	3	1	2
L_0	1.00 (1)	0.00 (0)	0.04 (0)	0.96 (1)	0.02 (0)	0.25 (0)	1.00 (1)	0.05 (0)	0.02 (0)
M_0	0.95 (1)	0.04 (0)	0.06 (0)	0.89 (1)	0.00 (0)	0.16 (0)	0.99 (1)	0.10 (0)	0.10 (0)
H_0	0.99 (1)	0.09 (0)	0.13 (0)	0.98 (1)	0.01 (0)	0.23 (0)	0.95 (1)	0.11 (0)	0.10 (0)
M_+	1.00 (1)	0.05 (0)	0.14 (0)	0.98 (1)	0.03 (0)	0.34 (1)	0.98 (1)	0.25 (0)	0.21 (0)
H_+	0.99 (1)	0.10 (0)	0.16 (0)	0.97 (1)	0.06 (0)	0.38 (1)	0.93 (1)	0.24 (0)	0.13 (0)
	Good 2 for			Good 3 for			Good 1 for		
(δ_m, Q)	1	0	3	2	0	1	3	0	2
L_0	0.99 (1)	0.79 (1)	0.36 (1)	0.99 (1)	0.88 (1)	0.99 (1)	0.98 (1)	0.78 (1)	0.13 (0)
M_0	0.99 (1)	0.80 (1)	0.24 (1)	0.99 (1)	0.94 (1)	0.96 (1)	0.99 (1)	0.73 (1)	0.15 (0)
H_0	0.99 (1)	0.82 (1)	0.32 (0)	1.00 (1)	0.89 (1)	0.99 (1)	1.00 (1)	0.83 (1)	0.17 (0)
M_+	1.00 (1)	0.74 (1)	0.28 (0)	0.99 (1)	0.86 (1)	0.99 (1)	0.98 (1)	0.54 (1)	0.30 (0)
H_+	1.00 (1)	0.69 (1)	0.21 (0)	1.00 (1)	0.90 (1)	0.99 (1)	0.98 (1)	0.50 (1)	0.25 (0)
	Good 3 for			Good 1 for			Good 2 for		
(δ_m, Q)	1	0	2	2	0	3	3	0	1
L_0	0.98 (1)	0.68 (1)	0.39 (0)	0.99 (1)	0.57 (1)	0.09 (0)	1.00 (1)	0.67 (1)	0.53 (1)
M_0	1.00 (1)	0.67 (1)	0.63 (0)	1.00 (1)	0.60 (1)	0.01 (0)	0.90 (1)	0.67 (1)	0.55 (1)
H_0	1.00 (1)	0.54 (1)	0.43 (1)	0.97 (1)	0.44 (1)	0.04 (0)	1.00 (1)	0.54 (1)	0.40 (1)
M_+	1.00 (1)	0.61 (1)	0.39 (1)	0.99 (1)	0.35 (0)	0.03 (0)	1.00 (1)	0.43 (1)	0.45 (1)
H_+	1.00 (1)	0.62 (1)	0.75*(1)	1.00 (1)	0.23 (0)	0.09 (0)	0.89 (1)	0.49 (1)	0.67 (1)

Notes. (1) A 100% predicted frequencies of offers is indicated with (1); no predicted offers are indicated with (0). (2) (*) means fewer than 5 observations. (3) Good 0 refers to fiat money. (4) The Online Appendix C contains two similar tables: one calculated on the first five rounds (Table C.5) and the other on the remaining rounds (Table C.6). (5) The description of the column (δ_m, Q) is in Table 1.

money or goods 2 or 3 for good 1 at a frequency between 97% and 100% across the five treatments. This outcome is not surprising and indicates that most subjects understood the basic structure of the payoff and that this motivated them to play the game.

Money quantity and speculative behavior (Hypothesis 1). The model predicts that, in absence of an inflation tax, speculative strategies are more likely to occur when the stock of money, Q, is low. Conversely, a high Q would lead to a greater likelihood of fundamental strategies being observed. Table 6 reveals that in treatments L_0, M_0, and H_0, type 1 tends to trade good 2 for good 3 at frequencies below 50%. This suggests that fundamental strategies are more likely to be observed, regardless of the level of Q. However, the table also shows that the frequency of speculative behavior is lower in M_0 and H_0 compared to L_0, a possible indication that the availability of fiat money may further discourage some individuals from pursuing speculative strategies. For instance, type 1 players trade of good 2 for good 3 L_0 at a frequency of 0.40, whereas in M_0 and H_0 is 0.23 and 0.24, respectively. In the same treatments they trade 3 for 2 at a frequency of 0.29, 0.69, and 0.50, respectively (see Table 6).

Acceptability of fiat money (Hypothesis 2). Participants showed a strong preference for accepting fiat money in the treatments without the inflation tax (L_0, M_0, and H_0). Type 1 subjects, for instance, frequently offer good 2 in exchange for fiat money, with a frequency range of 77% to 84%. Type 2 and type 3 subjects exhibit similar tendencies, with frequency ranges of 79% to 95% and 72% to 89%, respectively, as shown in Table 6 panels I-III. Another indication of the strong preference for fiat money is the low frequency at which participants use fiat money to acquire a good other than their consumption good. For example, type 1 subjects engage in this behavior in only 12% of cases. These findings confirm the existence of monetary equilibria, even with decreased storage costs for goods 2 and 3 compared to Duffy and Ochs (2002). Despite a significant decrease in storage costs, fiat money remains widely accepted.

The lab experiments suggest that the frequency at which participants accept money is not correlated with the proportion of people holding it (see Table 6). Hence, our conjecture that an increase in the money supply reduces its acceptability is not supported by the experimental data. It is important to note that the model predicts 100% money acceptance across the entire money range [0,0.9]. Our conjecture is based on the observation that both $\Delta^2_{m,1}$ and $\Delta^3_{m,1}$ decline with Q (Fig. 2a), although they remain positive over the entire interval of $Q = [0,0.9]$, indicating full money acceptance. Duffy and Ochs (2002) formulated the opposite hypothesis based on similar observations: that the supply of money does not affect its acceptability. They conclude that, “[C]ontrary to the theory, there is some evidence that the acceptability of good 0 [fiat money] diminishes as m [the supply of money] increases” (Duffy and Ochs, 2002, p. 655). Nevertheless, even in their experiments, the evidence that the supply of money negatively affects its acceptability is rather weak. A review of their Table 7 reveals that the acceptance of money is not significantly different in experiments with a medium or high money supply ($m = 1/3$ and $m = 1/2$) compared to those with a low supply ($m = 1/4$). Only in experiments with $m = 1/2$ does there appear to be a slightly lower acceptance of fiat money relative to corresponding experiments with $m = 1/3$

Inflation and speculative trading behavior (Hypothesis 3). The frequency distributions in the raw experimental data reveal no evidence of the inflation tax affecting the buying and selling decisions of type 1 study participants. The behavior of type 1 subjects in

Table 7
Welfare and Consumption (in utils) per Period, Laboratory Experiments.

(δ_m, Q)	C_1	W_1	C_2	W_2	C_3	W_3	C	W	$\hat{W}$
L_0	28.08	152.9	25.35	122.5	26.13	215.1	26.52	163.5	163.5
M_0	21.58	108.6	19.89	87.6	21.06	163.2	20.80	119.8	119.8
H_0	16.25	80.3	15.34	72.6	14.3	104.9	15.34	86.0	86.0
M_+	21.19	120.5	21.19	103.1	21.71	188.8	21.32	137.5	178.4
H_+	12.48	48.5	13.52	38.2	14.69	82.7	13.52	56.5	105.6

Notes. (1) The average number of periods within the same treatment, starting from L_0 and going down, are: 11.40, 10.47, 8.27, 13.53, and 9.40, respectively. (2) Table 7 implies the following ratios of W_1, W_2, W_3, and W on M_+ relative to M_0: 1.11, 1.18, 1.16, and 1.15 respectively; The corresponding ratios of H_+ relative to H_0 are 0.60, 0.53, 0.79, and 0.66. (3) For comparison with economy with continuum of agents see Table 3. (4) The description of the column (δ_m, Q) is in Table 1.

trading good 2 for good 3 remained consistent across treatments M_0 and M_+, as shown in the middle and bottom sections of Table 6 panel I. This observation contradicts the model's prediction that inflation would decrease speculative behavior for a medium stock of money ($Q = M$).

Inflation and the acceptability of fiat money (Hypothesis 4). The study participants' acceptance of money clearly showed sensitivity to the inflation tax. As inflation increased, the frequency of exchanging fiat money for commodities, other than the consumption good, rose for all three types of agents, while the frequency of exchanging commodities for fiat money decreased. This can be observed by comparing the frequencies in treatments M_0 to those in treatments M_+ and in treatments H_0 to those in treatments H_+.

Learning. We explored evidence of learning by calculating the frequencies of trade shown in Table 6 for the first and second halves of the trade sessions (see Tables C.5 and C.6 in Online Appendix C). There is evidence of learning regarding the acceptance of money in the presence of seigniorage. In M_+, the model predicts that type 2 agents value good 1 more than fiat money. In M_+, the frequency at which type 2 participants offer good 1 for money decreases from 0.5 to 0.29 between the first and second halves of the treatment, while the frequency of type 2 trading in the opposite direction increases from 0.26 to 0.37. However, we did not observe learning in speculative or fundamental strategies, as frequencies remained similar across treatment halves. It remains an open question whether providing larger incentives for type 1 players to engage in speculative strategies—such as lowering the carrying cost of good 3 to be close to that of good 2—might result in a significant increase in instances where type 1 trades good 3 for good 2.[9]

5.3. *Welfare in laboratory experiments*

In this section, we compare the welfare results of laboratory experiments with those implied by the model. As in Section 3.4, we focus on the welfare effects of the inflation tax. Specifically, we relate the cost of the inflation tax, the distortionary effects of inflation, and the welfare changes observed in the lab to those calculated for the corresponding steady state equilibria. Section 5.4 compares our key welfare findings to those from complementary works based on New Monetarist models.

We obtain the value corresponding to $V_{i,j}$ in the continuum agent model using the cross-session averages of cumulative payoffs of a type i participant who initially holds good j. This calculation excludes the initial 150 points assigned to laboratory participants at the beginning of the session and considers the payoff recorded at the random termination of the trading round. We combine these payoffs with the initial distribution of commodities among the 18 agents (Table 5) to obtain the laboratory estimate of per capita welfare, W, W_i, and $\hat{W}$ (Table 7). Table 7 also presents per-period consumption per type and for the overall economy in utility terms, C and C_i. [10]

In four out of five treatments, namely L_0, M_0, H_0, and H_+, the laboratory flows of consumption C and C_i are similar to those of the corresponding steady state equilibria. The value of C in the treatments L_0, M_0, H_0, and H_+ is 26.52, 20.80, 15.34, and 13.52, respectively, compared to 28.34, 23.14, 14.17, and 13.00 in the corresponding steady states. Additionally, the per capita payoffs in the four treatments are close to the welfare W in the corresponding steady states (see Tables 3 and 7). However, a notable deviation exists between the theoretical prediction and the laboratory experiment regarding treatment M_+. In M_+, the payoff is 137.5, roughly double that of the steady state M_+ and larger than the per capita payoff in M_0. The randomness of game termination partly explains the unusually high payoff in M_+. The average number of periods in M_+ treatments is 13.53, compared to 10.47 in M_0 (with the average number of periods across all treatments being 10.6). However, the extended duration of M_+ sessions does not entirely explain the gap between predicted and observed payoffs. Per-period consumption is 14% larger than predicted (21.32 vs. 18.07) and slightly higher than in M_0. In summary, when comparing treatments M_0 and M_+, seigniorage does not seem to limit the intensity of trade and may even stimulate it.

[9] Earlier experiments by Duffy and Ochs (2002), however, suggest that even when parameter values are set to create the most favorable conditions for the emergence of speculative strategies, these strategies are not easily adopted in the laboratory. For instance, in their Case (2), which was designed to promote a speculative equilibrium, there is only a marginal difference between the carrying costs of goods 2 and 3 ($c_2 = 23$, $c_3 = 24$), and a strong liquidity advantage for good 3. Although the frequency of speculative strategies they observe is higher than ours, in some treatments it is around 50% or lower (see their Table 9).

[10] We calculated Table 5 as an approximation of the initial distribution $p_{i,j}$ of the corresponding theoretical steady states of Table 2. The rounding to unity introduces a potential gap between the lab payoffs and the theoretical steady state results.

Turning to the welfare effects of the inflation tax, in Section 3.4, we distinguished between the cost of holding balances, the surplus agents gain from selling commodities to the government, and the production distortion possibly caused by seigniorage. In the theoretical steady states equilibria M_+ and H_+, we concluded that the seigniorage cost as a fraction of consumption, τ, is 7.2% and 15.1%, respectively. The cost associated solely with reproducing the confiscated good, τ_D, which excludes the capital loss of replacing fiat money with a less valuable asset, is 4.4% and 10.2% of the flow of consumption, respectively. We estimated the moments of τ_D in the treatments M_+ and H_+ as 4.3% and 11.6%. The lack of lab information on the capital loss caused by inflation prevent us from estimating τ_i and the gains g_i. However, for the steady state equilibria we concluded that g_i is approximately equal to the (negative of) capital loss component in τ, making τ_D a good approximation of the cost of inflation for the average individual (see the last three columns of Table 4). Assuming a similar property holds in the lab, the cost of the inflation tax in treatments M_+ and H_+ is 4.3% and 11.6% of the flow of consumption.

These considerations lead to the conclusion that in M treatments, contrary to prediction, seigniorage does not appear to reduce production. In fact, output is 2.5% larger in M_+ than in M_0. The inflation tax, however, reduces average consumption when there is a high supply of money, as predicted by the theory. In the lab, average consumption decreases by 11.86%, while the theory predicts a decline of 8.26% (Tables 3 and 7).

The welfare results from the lab closely align with theoretical predictions when transitioning from treatment H_0 to H_+. The ratios of W_1, W_2, W_3, and W in H_+ relative to H_0 are 0.60, 0.53, 0.79, and 0.66, respectively (see Table 7). The corresponding ratios implied by the model are 0.68, 0.50, 0.76, and 0.69, respectively (see Table 3). However, the inflation tax did not induce type 1 agents to switch from a speculative to a fundamental strategy when moving from M_0 to M_+, as predicted by the model. Consequently, the changes in laboratory welfare significantly diverge from those implied by the model. For example, seigniorage leads to a 14.77% increase in welfare, whereas the theory predicts a 39% decline. Furthermore, we observe that the laboratory welfare data are consistent with the notion that type 1 agents do not switch trading strategies, as the percentage changes in welfare when transitioning from M_0 to M_+ are similar across all three types.

5.4. Discussion

Anbarci et al. (2015) and Jiang et al. (2023) have investigated the effects of an inflation tax in the laboratory, adapting the search models of Rocheteau and Wright (2005) and Lagos and Wright (2005). One important difference between these models and our environment is that in the former, the inflation tax erodes real balances through an increase in prices, whereas in our work, it does so directly through government confiscation. Another difference is that the distortion of production in our environment is due to a slowdown in the intensity of trade, whereas in Anbarci et al. (2015) and Jiang et al. (2023), it is driven by the intensive margin.

There are also differences in the laboratory design. Of the three laboratory scenarios in Jiang et al. (2023), ours resembles the one in which inflation is produced through government spending. While in Jiang et al. (2023) fiat money grows from one period to the next, in our scenario, it remains constant. In this sense, our design is closer to Anbarci et al. (2015), where there are no explicit changes in the supply of money. Another similarity with Anbarci et al. (2015) is that money holding is costly: in their study, because subjects are asked to pay interest on money borrowed to finance their consumption; in ours, money holders are subject to random confiscation. Thus, in Anbarci et al. (2015), as in our experiments, subjects are clearly facing an inflation tax. In Jiang et al. (2023), participants have to infer the inflation tax through the increase in prices.

Table 9 compares our key findings about welfare changes and production distortion associated with the inflation tax to those of Anbarci et al. (2015) and Jiang et al. (2023). We consider the scenario of 15% inflation with government spending from Jiang et al. (2023) and the 5% inflation scenario from Anbarci et al. (2015) – we take an average of their results for the 3x2 and 2x2 markets – as these are the closest designs to our 8% seigniorage rate experiments. In Anbarci et al. (2015), a one percent inflation causes a decline in production, both in theory and in the lab, of between 2 and 2.5 percent, and a drop in welfare in the lab by 1 percent. In Jiang et al. (2023), a one percent increase in money supply causes production to shrink by about 1.5% in theory and 2% in the lab. Welfare, however, is not as sensitive to inflation, as it goes down by less than 0.5% both in theory and in the lab.

We compare these outcomes with our scenario where $Q = H$, where experimental results align with theoretical predictions. In such a scenario, production declines by approximately 1% in theory and 1.5% in the lab per 1% of seigniorage, which is lower than the findings of Anbarci et al. (2015) and Jiang et al. (2023). In our environment, seigniorage induces type 2 to drop the acceptance of fiat money for good 1. Therefore, the relatively modest production distortions are due to the reduced liquidity of fiat money that slows down trade and production. In summary, within the New Monetarist framework, inflation-induced production distortions appear to be more pronounced compared to those predicted by the KW model. Conversely, we observe larger reductions in welfare, both theoretically and empirically, compared to the findings of Jiang et al. (2023) and Anbarci et al. (2015). Specifically, in our study, average welfare decreases by 4%, whereas in the aforementioned papers, the decline is around 0.4% and 1%, respectively. We hypothesize that the relatively steeper decline in welfare in our model is due to the storage costs inherent in the KW environment, which exert greater influence in equilibria characterized by fewer exchanges.

Finally, it is important to point out that from the outcome of the lab experiments, one cannot infer whether participants developed some level of cooperation. The theoretical model assumes that subjects trade when both gain a static surplus; we did not explore equilibria with dynamic incentives. In particular, we assumed limited commitment and imperfect information. Because trade occurs also against another asset, there is an implicit assumption that an agent cannot acquire a good with a promise for future production, presumably because they can renege on the promise. If trading histories are observable, however, and there are credible punishments for not honoring a production promise, credit equilibria may emerge; these equilibria do not require the use of money and are possibly more efficient (see Kehoe and Levine, 1993, and Kocherlakota, 1998).

While monitoring trading histories in an environment with an infinite number of agents is impractical, social norms and contagion strategies can enforce credit in a small society. In small groups, when someone fails to honor a production promise, others may be tempted to do the same, leading to the punishment of the original deviant (Araujo, 2004). Our laboratory experiments and instructions provided to subjects are not explicitly designed to test the emergence of trading schemes informed by gifts or credit relationships. However, we attempted to assess whether the resulting payoffs in the lab align more closely with a monetary equilibrium or a gift exchange equilibrium. First, we computed a gift exchange equilibrium in the economy with a continuum of agents and then simulated an economy with 18 computer agents without money, assuming gift-exchange relationships. In our gift exchange equilibrium, trade occurs when one party holds the other's consumption good. While this trade can significantly boost the utility of the party receiving their consumption good, the other party may face increased storage costs. Excluding liquidity considerations (which may apply only to type 1 individuals), the party exchanging the commodity for one with higher storage costs may be motivated by the expectation that, in a future trade, the other party will reciprocate when holding their consumption good. We then compare the consumption and payoffs in the L_0 treatments observed in the lab with those of the L_0 (monetary) steady state and with those of such a gift-equilibrium. We also perform a similar comparison with the 18 computer-agent economy (see Table 10). The comparison suggests that interactions in the lab are more likely to approximate a monetary than a gift exchange equilibrium. For instance, the flow of consumption in the lab is 94% of that predicted by the theoretical monetary equilibrium, but only 61% of the credit equilibrium. The corresponding ratios with the 18 computer-agent economy are 88% and 58%. Similar conclusions follow from comparing welfare ratios. Future work may shed light on whether changes in the number of agents, variations in their type composition, or other alterations to the KW environment make the emergence of gift-giving exchanges more likely. Nevertheless, it is worth noting that the outcome of our simple comparison between laboratory experiments and data generated through monetary and gift exchange schemes aligns with the findings of Duffy and Puzzello (2014), who concluded that, within a Lagos and Wright (2005) framework, it is easier for participants to coordinate on a monetary equilibrium than to adopt gift-giving social norms.

6. Statistical analysis

In this section, we use statistical tools to analyze experimental data. Our objective is to determine whether the aggregate experimental data from Table 6 (in Section 5.2) align with the results of a statistical analysis that accounts for the variability in individual choices made by people of the same type in similar trade situations. The literature offers various methods for addressing this issue (for a review, see Moffatt, 2016). Our approach is to first analyze the experimental data using a simple statistical model that closely captures the behavioral assumptions of the theoretical environment. We then extend the model to explore heterogeneity among agents.

Suppose that participants are all alike, in the sense that in similar circumstance act in the same way, according to incentives of their personal payoffs. Nevertheless, individuals can also make mistakes and choose the opposite strategy of what would be the optimal one. One objective of the statistical analysis is to estimate the probability that individuals adopt a given trading strategies, and how such probability changes with seigniorage and with the quantity of money. We then turn the statistical analysis to test the four predictions of the model outlined in Section 3.4 (H1-H4). We use the following notation in this section. Let $s_1(i,T)$ denote the likelihood that an individual of type i trades good $i+1$ for money, m, and $s_2(i,T)$ indicate the likelihood that a type i individual trades good $i+2$ for m in treatment T. Let $s_3(i,T)$ signify the likelihood that a type i individual trades $i+1$ for $i+2$ in treatment T. We use $N_1(i,T)$ to symbolize the number of opportunities type i individuals had in treatment T to trade good $i+1$ for money, and $n_1(i,T)$ to stand for the number of times they chose to trade. In this situation, $n_1(i,T)$ is described by a binomial distribution with parameters $N_1(i,T)$ and $s_1(i,T)$, that is

$$\mathbb{P}\left(n_1(i,T)=n \,\middle|\, N_1(i,T)=N\right)=\binom{N}{n}s_1(i,T)^n\left(1-s_1(i,T)\right)^{N-n}. \tag{5}$$

The Method of Moments (MM) estimator for $s_1(i,T)$ is calculated as $\tilde{s}_1(i,T)=n_1(i,T)/N_1(i,T)$ (see Chapter 7.2 of Devore, 2010). Based on this, speculation level in treatment T can be calculated as

$$\tilde{s}_1(3,T)=n_1(3,T)/N_1(3,T). \tag{6}$$

Similar equations can be derived for the MM estimators of $s_2(i,T)$ and $s_3(i,T)$. Table 11 lists the estimators' values, along with their confidence intervals, for the five laboratory treatments L_0, M_0, H_0, M_+, and H_+.

In Section 5.2, we argued that the summary statistics in Table 6 provide evidence, in line with Hypothesis 1, that an increase in the stock of fiat money discourages individuals from pursuing speculative strategies. Specifically, Table 6 suggests that the frequency of speculative behavior is lower in M_0 and H_0 compared to L_0. A second finding was that participants showed a strong preference for accepting fiat money in treatments without the inflation tax, and that money acceptance is not correlated with the money supply. Thus, the summary statistics suggest the existence of monetary equilibria across the entire range of the stock of money (Hypothesis 2). A third finding in Section 5.2 is that, contrary to Hypothesis 3, the raw data reveal no evidence that the inflation tax alters the fundamental or speculative behaviors of type 1 individuals. The fourth key implication of Table 6 is that, in line with Hypothesis 4, the inflation tax lowers the acceptability of money. These four main conclusions derived from the summary statistics are largely consistent with the MM estimators.

The probability of accepting money, as shown in $\tilde{s}_1(i,T)$ and $\tilde{s}_2(i,T)$, is generally high for all types and often exceeds 50%. However, type 1 individuals select speculative strategies with a probability $\tilde{s}_3(1,T)$ that tend to be below 50%. By comparing the trading probabilities across treatments, we gain insight into how individuals respond to the inflation tax and the quantity of money in the system. Table 11 reveals that the quantity of money does not seem to alter the acceptance of money in the treatments without an inflation tax, L_0, M_0, H_0. Nonetheless, as we move from L_0 to M_0 or from L_0 to H_0, we observe a decrease in the probability of type 1 individuals engaging in speculative strategies, $\tilde{s}_3(1,T)$. But this probability increases when moving from M_0 to H_0.

To further examine the differences in data from various treatments, we perform a series of hypothesis tests for the statements H1-H4 outlined in Section 3.4. H1 posits that type 1 individuals are less likely to engage in speculative behavior with an increase in the quantity of fiat money. This means that type 1 individuals are less likely to speculate in $T = M_0$ compared to $T = L_0$, or $s_3(1,M_0) < s_3(1,L_0)$. To test this, we establish a null hypothesis of $h_0 : s_3(1,M_0) \geq s_3(1,L_0)$ against the alternative hypothesis $h_a : s_3(1,M_0) < s_3(1,L_0)$. Rejection of h_0 supports H1, and a low p-value indicates a high level of statistical confidence in the rejection of h_0. We calculate p-values using the large sample tests for the statistics.

$$z = \frac{\tilde{s}_3(1,M_0) - \tilde{s}_3(1,L_0)}{\sqrt{\tilde{s}(1-\tilde{s})\left(\frac{1}{N_3(1,M_0)} + \frac{1}{N_3(1,L_0)}\right)}}, \tag{7}$$

where

$$\tilde{s} = \tilde{s}_3(1,M_0)\frac{N_3(1,M_0)}{N_3(1,M_0)+N_3(1,L_0)} + \tilde{s}_3(1,L_0)\frac{N_3(1,L_0)}{N_3(1,M_0)+N_3(1,L_0)}.$$

The distribution of z is approximated with a normal distribution because of the Central Limit Theorem (see, among others, Devore, 2010, Chapter 9.4).

The results of these tests are reported in Table 12. The null hypothesis h_0 that $s_3(1,M_0) \geq s_3(1,L_0)$ received a small p-value of 0.001, which supports H1's statement that type 1 speculative behavior decreases with the quantity of fiat money. However, the results are not as clear-cut when comparing treatments with differing amounts of money, keeping the same inflation rate. For instance, the p-values obtained in the comparisons between H_0 and L_0, and H_0 and M_0 are high, at 0.181 and 0.898 respectively. In conclusion, the results summarized in Table 12 suggest that fiat money reduces type 1 individuals' inclination towards speculation in two out of four treatment comparisons.

We studied the consequences of the quantity of money on the acceptance of money by type 2 and type 3 agents by testing their behavior when trading good 1, which has the lowest storage cost, for money. Our results tend to support H2's statement that money acceptance decreases with the quantity of money, as we rejected the null hypothesis in three out of four pairwise treatment comparisons (i.e., L_0 vs H_0, and M_0 vs H_0) with p-values between 0.001 and 0.073. However, in the L_0 vs M_0 comparison, the p-value of 0.887 showed no significant difference in money acceptance, in fact, the money acceptance difference had the opposite sign from what we hypothesized. Type 3 agents showed little responsiveness to the quantity of money, with only a low p-value of 0.050 observed in the L_0 vs M_0 comparison. There was no evidence in the other two comparisons (L_0 vs H_0, and M_0 vs. H_0) that the stock of money in circulation influenced type 3's evaluation of fiat money, with two out of three estimates carrying an opposite sign.

The hypothesis tests for the H3 statement that inflation reduces type-1 speculative behavior produce inconsistent results. The p-value for the comparison between H_0 and H_+ is 0.05, but the p-value for the comparison between M_0 and M_+ is 0.921, which is very high.

Finally, the experimental data firmly supports the H4 statement that inflation decreases individuals' appraisal of money. In both type 2 and type 3 agents, small p-values were obtained when comparing their acceptance of fiat money in inflating and non-inflating scenarios (as shown in the bottom section of Table 12).

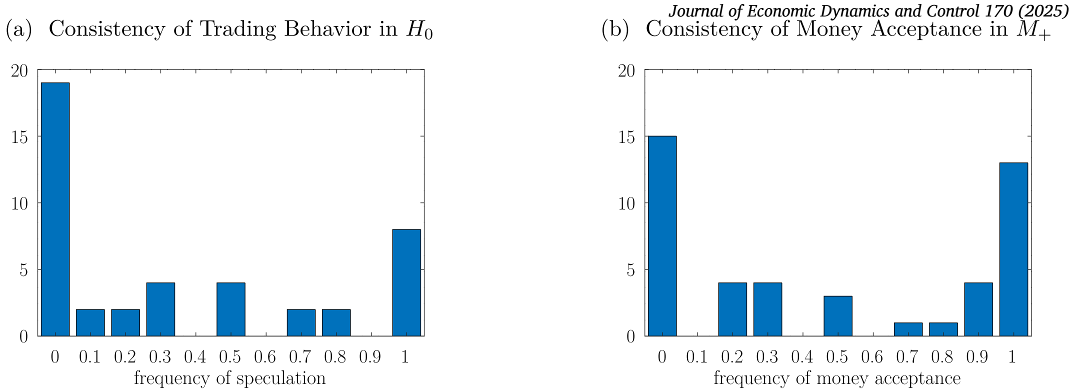
7. Robustness of the statistical analysis

In line with the economic model environment, the statistical analysis in the previous section assumes that individuals have the same decision-making process regarding trading strategies. However, in experimental studies it is common to account for heterogeneity in people's choices. People may differ in their ability to maximize payoffs, perceive time-horizons, or willingness to take the risk of a speculative trade. While individual characteristics such as decision-making abilities and perception of time-horizon cannot be directly observed, a closer examination of experimental data may provide insight into the possibility of refining results with further statistical analysis.

Fig. 4a illustrates the decisions made by 43 type 1 agents in treatment M_0. These agents had to choose between goods 2 and 3 in multiple periods. Out of the 43 individuals, 19 consistently favored good 2, 8 consistently favored good 3, and the remaining 15 individuals demonstrated ambiguity in their choices, favoring one good over the other half of the time. Similarly, Fig. 4b displays a bimodal distribution for type 2 agents in their choice between good 1 and fiat money in treatment H_+. These observations suggest that even agents of the same type in similar circumstances may take opposing trading decisions. Next, we then present a statistical model that allows for two individuals of the same type to take opposite strategies in similar circumstances.

7.1. A mix of two binomial distributions

Suppose at the start of the game, a fraction $q_1(T)$ of type 1 individuals in treatment T choose a speculative strategy, while the remaining $1 - q_1(T)$ choose a fundamental strategy. These individuals may deviate from their pre-set strategies with a probability



Notes. Panel (a) shows that in treatment H_0, 19 type 1 players always played fundamental strategies, while 8 always played speculative strategies. Panel (b) shows that in treatment M_+, 15 type 2 agents always used money to buy good 1, while 13 never did. A few individuals did not consistently play one strategy or the other.

Fig. 4. A Sample of Laboratory Observations.

of $p_1(T)$. These deviations could result from either random mistakes or strategic decisions made based on information about the economy that participants can view on their screens.

Denote the number of opportunities for type 1 individual a to participate in an exchange between goods 2 and 3 in treatment T as $N_1(a,T)$. Let $n_1(a,T)$ be the number of times this individual chooses good 3 over good 2. The distribution of $n_1(a,T)$, given $N_1(a,T)$, can be expressed as a combination of two binomial distributions:

$$\mathbb{P}\big(n_1(a,T)=n,\big|, N_1(a,T)=N\big)= \\ q_1(T)\binom{N}{n}p_1(T)^n\big(1-p_1(T)\big)^{N-n}+(1-q_1(T))\binom{N}{n}p_1(T)^{N-n}\big(1-p_1(T)\big)^n. \tag{8}$$

We use Generalized Method of Moments (GMM) estimators, $\hat{p}_1(T)$ and $\hat{q}_1(T)$, to compute the probability that type 1 agents choose a speculative strategy. This probability is expressed as

$$\tilde{s}_1(3,T)=\tilde{p}_1(T)\tilde{q}_1(T)+(1-\tilde{p}_1(T))(1-\tilde{q}_1(T)). \tag{9}$$

In a similar fashion, we calculated the probabilities of money acceptance with regards to good 1 for both type 2 agents ($\hat{s}_2(2,T)$) and type 3 agents ($\hat{s}_3(3,T)$).

Table 13 compares these estimates to those obtained from the baseline statistical analysis, $\hat{s}_3(1,T)$, $\hat{s}_2(2,T)$, and $\hat{s}_1(3,T)$. The estimates of speculative behavior and money acceptance, calculated with the mixture of two binomial distributions and reported in Table 13, are comparable to those obtained through the basic statistical analysis (Table 11). Table 13 reveals that the speculative probability in L_0, calculated using the two binomial distribution functions, is 0.35, which is close to the 0.41 calculated from the baseline statistical model. Nevertheless, calculating the probability of a strategy as an average of probabilities offers a deeper understanding of how people made their decisions. As shown in Table 13, the speculative probability of 0.36 is composed of an estimated 0.27 fraction of people who chose a speculative strategy and a 17% deviation from the original strategy, whether it was the fundamental or speculative strategy.

7.2. Normal random variable

A different way to take into account heterogeneity among participants is to incorporate it through a continuous variable. Suppose that a type 1 individual a in treatment T, decides on a trade of good 2 for good 3 by comparing the outcome of a normally distributed noise, ϵ, with a personal threshold $\Gamma_1(a,T)$. The noises ϵ are independent among agents and time periods. The personal threshold is given by $\Gamma_1(T,a)=D_1(T)+b_1(a)$, where $D_1(T)$ represents type 1's tendency to speculate in treatment T and $b_1(a)$ captures individual a's bias towards or against the speculative strategy. Individual a then has a probability of $\Phi\big(D_1(T)+b_1(a)\big)$, of preferring good 3 over good 2, where $\Phi(x)$ is the cumulative distribution function of a standard normal random variable. Due to the limited size of our data set, we cannot calculate $b_1(a)$ individually. So, we assume that $b_1(a)$ follows a normal distribution with a mean of zero and a variance of v_1. The parameter D_1 accounts for any deviation of $b_1(a)$ from its mean.

To estimate the average fraction of speculative choices for treatment T, we calculate $\bar{s}_1(3,T)$ as follows:

$$\bar{s}_1(3,T)=\int_{-\infty}^{\infty}\Phi\big(D_1(T)+b_1\big)\frac{1}{\sqrt{2\pi v_1}}e^{-b_1^2/2v_1}\,db_1. \tag{10}$$

Table 8
Inflation Tax, Distortion, and Welfare: Summary.

Panel A: Theory (% change)				
	τ_D	C	W	$\hat{W}$
M	4.43	-21.91	-39.00	-8.03
H	10.23	-8.26	-31.49	58.43
Panel B: Lab (% change)				
	τ_D	C	W	$\hat{W}$
M	4.27	2.50	14.77	48.91
H	11.63	-11.86	-34.30	0.23

Notes. (1) In Panel A, τ_D is taken from Table 4; the remaining variables are calculated from the last three columns of Table 3. (2) In Panel B, see text for calculation of τ_D; the remaining variables are calculated from the last three columns of Table 7.

Table 9
Distortion and welfare, per 1% Inflation Tax or Seignorage Rate.

Panel A: This paper			
		Production	Welfare
Theory	Eq.		
	M	-2.74	-4.88
	H	-1.03	-3.94
Lab	Tr.		
	M	0.31	1.85
	H	-1.48	-4.29
Panel B: Anbarci et al. (2015)			
		Production	Welfare
Theory		-2.32	N.A.
Lab		-2.50	-0.99
Panel C: Jiang et al. (2023)			
		Production	Welfare
Theory		-1.49	-0.48
Lab		-2.06	-0.32

Notes. (1) Our elaboration: Panel A based on Table 8; Panel B based on Anbarci et al., 2015, their Tables, 1, 2, 7 (average of 3x2 and 2x2 markets); Panel C based on Jiang et al. (2023), their Table 2 and their Figs. 2 and 3, 15% government spending vs. no inflation. (2) All figures are in percentages.

Similar probability functions describe the choices between fiat money and good 1 for type 2 and type 3 agents. These functions have parameters $(D_2(T),\ b_2(a))$ and $(D_3(T),\ b_3(a))$, where $b_2(a)$ and $b_3(a)$ are normally distributed with zero mean and variances of v_2 and v_3, respectively. By using these probability functions, we estimate $s_2(2,T)$ and $s_3(1,T)$.[11]

Table 14 presents the results of our statistical analysis for the estimates $s_1(3,T)$, $s_2(2,T)$, and $s_3(1,T)$. It shows that the fraction of type one individuals who speculate, $\bar{s}_1$, decreases from 0.35 to 0.28 when moving from L_0 to M_0, and from 0.31 to 0.17 when moving from M_+ to H_+. Conversely, the fraction increases from 0.28 to 0.31 when moving from M_0 to H_0. The pattern and size of these changes are in line with the findings of the previous two statistical methods, which are also summarized in the table for convenience. Table 14 also indicates that the estimates of money acceptance, $\bar{s}_2$ $\bar{s}_1$, are in line, and somewhat more marked, than what obtained with the other two statistical methods. We also find that the probit approach yields p-values for the null hypotheses similar to those shown in Table 12 for the baseline statistical analysis. We also analyzed the experimental data using the random effects probit model,

[11] The statistical model of Section 5 can be obtained as special case of the one outlined here by setting $b_i(a) = 0$. With this restriction, we have, for example, $s_3(1,T) = \Phi\big(D_1(T)\big)$.

Table 10
Monetary and Credit Economies.

Panel A: Lab vs. Theory		
	Production (C)	Welfare (W)
Monetary	0.94	1.21
Credit	0.61	0.74
Panel B: Lab vs. 18 Computer-agent Economy		
	Production (C)	Welfare (W)
Monetary	0.88	1.11
Credit	0.58	0.68

Notes. In Panel A, the C (W) column represents the ratio between the flow of consumption (per capita payoffs) in the L_0 lab treatment and the corresponding value in the monetary equilibrium and the credit equilibrium. Panel B depicts similar ratios relative to the 18 computer-agent economy.

Table 11
Estimators and 95% Confidence Interval (CI).

	Type 1					
Treatment	$\hat{s}_1$	CI	$\hat{s}_2$	CI	$\hat{s}_3$	CI
L_0	0.83	(0.76 , 0.87)	0.79	(0.66 , 0.87)	0.41	(0.35 , 0.46)
M_0	0.84	(0.81 , 0.87)	0.84	(0.77 , 0.90)	0.26	(0.20 , 0.34)
H_0	0.84	(0.80 , 0.87)	0.76	(0.67 , 0.83)	0.35	(0.24 , 0.46)
M_+	0.79	(0.75 , 0.83)	0.77	(0.69 , 0.82)	0.33	(0.27 , 0.40)
H_+	0.74	(0.70 , 0.78)	0.79	(0.71 , 0.85)	0.22	(0.13 , 0.33)
	Type 2					
Treatment	$\hat{s}_1$	CI	$\hat{s}_2$	CI	$\hat{s}_3$	CI
L_0	0.91	(0.85 , 0.95)	0.66	(0.59 , 0.73)	0.96	(0.94 , 0.98)
M_0	0.96	(0.93 , 0.98)	0.72	(0.66 , 0.77)	0.96	(0.93 , 0.98)
H_0	0.91	(0.88 , 0.94)	0.59	(0.53 , 0.65)	0.98	(0.92 , 0.99)
M_+	0.89	(0.85 , 0.92)	0.49	(0.43 , 0.54)	0.98	(0.95 , 0.99)
H_+	0.91	(0.88 , 0.94)	0.42	(0.37 , 0.48)	0.97	(0.91 , 0.99)
	Type 3					
Treatment	$\hat{s}_1$	CI	$\hat{s}_2$	CI	$\hat{s}_3$	CI
L_0	0.84	(0.79 , 0.88)	0.92	(0.85 , 0.96)	0.18	(0.14 , 0.22)
M_0	0.79	(0.75 , 0.83)	0.85	(0.79 , 0.90)	0.19	(0.14 , 0.24)
H_0	0.85	(0.81 , 0.88)	0.84	(0.78 , 0.89)	0.23	(0.14 , 0.34)
M_+	0.61	(0.57 , 0.65)	0.68	(0.62 , 0.74)	0.34	(0.28 , 0.40)
H_+	0.59	(0.55 , 0.63)	0.77	(0.69 , 0.83)	0.26	(0.18 , 0.36)

as for instance in Duffy and Puzzello (2022), and the multilevel model (see Moffatt, 2016). However, both approaches led to the same conclusions as our simpler statistical models.

8. Conclusion

Evaluating the effects of monetary policy is a challenging task that requires observing how individuals respond to it and understanding how microeconomic mechanisms are transmitted to the macroeconomy. In this study, we examined the consequences of a change in the quantity of money and the introduction of inflation in a KW search model, testing the predictions in laboratory experiments. Inflation is implemented by confiscating fiat money from randomly chosen money holders. The confiscated money is then reinjected into the economy to keep the money supply constant from one period to the next. The theoretical setup and its implementation in the laboratory with real participants allowed us to study the effects of introducing an inflation tax and changes in the quantity of money on welfare and output.

We distinguished between the negative wealth effects on money holders, the distortionary effects on output due to changes in trading strategies, and the expansionary effect associated with the reinjection of confiscated money. While in models with flexible prices, seigniorage reduces individuals' real wealth through price increases, in our work, where prices are fixed, wealth erosion occurs through the confiscation of fiat money. Unlike the New Monetarist models, the distortionary effects of the inflation tax on output are not due to changes in individual production effort intensity but are linked to changes in the liquidity of fiat money and other assets. In other words, this setup allowed us to emphasize a link between the monetary and real sides of the economy based on the liquidity of money and other commodities.

Table 12
Test of Hypotheses and p-values.

Hypothesis	h_0	z	p-value
H1			
(a)	$s_3(1, M_0) \geq s_3(1, L_0)$	2.99	0.001
(b)	$s_3(1, H_0) \geq s_3(1, L_0)$	0.91	0.181
(c)	$s_3(1, H_0) \geq s_3(1, M_0)$	-1.27	0.898
H2 type 2			
(a)	$s_2(2, L_0) \leq s_2(2, M_0)$	-1.21	0.887
(b)	$s_2(2, L_0) \leq s_2(2, H_0)$	1.45	0.073
(c)	$s_2(2, M_0) \leq s_2(2, H_0)$	3.1	0.001
H2 type 3			
(a)	$s_1(3, L_0) \leq s_1(3, M_0)$	1.65	0.050
(b)	$s_1(3, L_0) \leq s_1(3, H_0)$	-0.31	0.622
(c)	$s_1(3, M_0) \leq s_1(3, H_0)$	-2.22	0.987
H3			
(a)	$s_3(1, M_0) \leq s_3(1, M_+)$	-1.41	0.921
(b)	$s_3(1, H_0) \leq s_3(1, H_+)$	1.64	0.050
H4 type 2			
(a)	$s_2(2, M_0) \leq s_2(2, M_+)$	5.82	<0.001
(b)	$s_2(2, H_0) \leq s_2(2, H_+)$	4.02	<0.001
H4 type 3			
(a)	$s_1(3, M_0) \leq s_1(3, M_+)$	6.13	<0.001
(b)	$s_1(3, H_0) \leq s_1(3, H_+)$	8.14	<0.001

Notes. The column h_0 specifies the null hypothesis; z is the value of the statistics computed from the experimental data using (7).

Table 13
Estimates with Two Binomial Distributions.

	Speculative Behavior			Money Acceptance					
	$\hat{q}_1$	$\hat{p}_1$	$\hat{s}_3(1)(\tilde{s}_3(1))$	$\hat{q}_2$	$\hat{p}_2$	$\hat{s}_2(2)(\tilde{s}_2(2))$	$\hat{q}_3$	$\hat{p}_3$	$\hat{s}_1(3)(\tilde{s}_1(3))$
L_0	0.27	0.17	0.35(0.41)	0.63	0.09	0.60(0.66)	0.80	0.07	0.76(0.84)
M_0	0.12	0.15	0.23(0.26)	0.69	0.06	0.67(0.52)	0.82	0.09	0.76(0.79)
H_0	0.34	0.12	0.38(0.35)	0.67	0.09	0.64(0.59)	0.90	0.08	0.83(0.85)
M_+	0.23	0.16	0.31(0.33)	0.56	0.15	0.54(0.49)	0.70	0.14	0.65(0.61)
H_+	0.05	0.12	0.16(0.22)	0.60	0.13	0.58(0.42)	0.69	0.15	0.64(0.59)

Notes. $\hat{q}_1(T)$ is the probability that a type 1 chooses good 3 over good 2; $\hat{p}_1(T)$ is the probability that this individual deviates from that decision; $\hat{s}_3(T)$ is the average probability of speculative behavior; $\tilde{s}_3(T)$ is copied from Table 11 for comparison purposes.

Table 14
Normal Distribution and Comparison Across Statistical Models.

	$\bar{s}_3(1,T)$	$\hat{s}_3(1,T)$	$\tilde{s}_3(1,T)$	$\bar{s}_2(2,T)$	$\hat{s}_2(2,T)$	$\tilde{s}_2(2,T)$	$\bar{s}_1(3,T)$	$\hat{s}_1(3,T)$	$\tilde{s}_1(3,T)$
L_0	0.35	0.35	0.41	0.63	0.60	0.66	0.77	0.76	0.84
M_0	0.28	0.23	0.26	0.72	0.67	0.52	0.77	0.76	0.79
H_0	0.31	0.38	0.35	0.66	0.64	0.59	0.81	0.83	0.85
M_+	0.31	0.31	0.33	0.53	0.54	0.49	0.62	0.65	0.61
H_+	0.17	0.16	0.12	0.49	0.58	0.42	0.62	0.64	0.59
	$\tilde{v}_1 = 1.59$			$\tilde{v}_2 = 2.79$			$\tilde{v}_3 = 1.80$		

Notes. (1) The columns $\bar{s}_i$, $\hat{s}_i$, and $\tilde{s}_i$ report probit estimates obtained with the normal distribution model, the two-binomial distribution model (Table 13), and the baseline model (Table 11), respectively. (2) $\tilde{v}_i$ is the estimated variance of $b_i(a)$ for the probit model.

For a given specification of preferences, search intensity, and production technology, we characterized the existence of fundamental and speculative equilibria with full or partial acceptance of money over a range of money supply and seigniorage rates. By doing so, we could illustrate the separate roles of the inflation tax and the quantity of money in equilibrium selection. Our set of parameters implied that in a region where a low proportion of individuals hold money and there is no seigniorage, speculative equilibria emerge. Conversely, when a large fraction of individuals hold money, the low-storage-cost good rivals fiat money more strongly in its role as a means of payment, and the liquidity value of the high-storage-cost good drops. As a result, the economy coordinates on a fundamental equilibrium. Similar mechanisms, albeit stronger, are triggered by the introduction of an inflation tax.

Although the KW environment is relatively simple, and it is easy for the participants in the lab to learn its details, the microeconomic interactions are rich and difficult to anticipate because individual trading choices respond to the distribution of fiat money and commodities across the population. We tested the mechanisms described above by comparing the outcomes of five treatments that differed in the quantity of money or the rate of seigniorage. Departing from the theory's predictions, participants' acceptance of money was not correlated with the proportion of participants holding money, and inflation did not appear to alter their speculative or fundamental behavior. In line with the theory's predictions, the inflation tax had a clear negative effect on their decision to accept money. Nevertheless, in no treatment did a non-monetary equilibrium replace a monetary one—an occurrence that, given the self-referential nature of money, cannot be ruled out a priori.

While in the KW model, the inflation tax may generate larger output and welfare losses than in search models with flexible prices, the results from our laboratory experiments were comparable to, albeit more pronounced than, the recent works of Anbarci et al. (2015) and Jiang et al. (2023), which based their analyses on New Monetarist models. Future research can delve further into closely aligning the theoretical environment and experimental design, as emphasized by Jiang et al. (2024). We also believe that the methodology developed in this work can serve as a foundation to bridge the gap between old and new generations of search monetary models, so that the real effects of liquidity can have a more prominent role in connecting the monetary and real sides of the economy.

Appendix A. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jedc.2024.105031.

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