Carnegie-Rochester Conference Series on Public Policy 43 (1995) 111-156
North-Holland

Does a constant money growth rule help stabilize inflation?: experimental evidence*

Ramon Marimon[†]

Dept. of Economics, European University Institute, Badia Fiesolana,

I-50016 San Domenico di Fiesole, Firenze, Italy

and

Universitat Pompeu Fabra, Barcelona

and

Shyam Sunder

Carnegie Mellon University, Pittsburgh, PA 15213

Abstract

We design and study the behavior of experimental overlapping generations economies in which the government either finances real deficits through seigniorage or allows money supply to grow at a predetermined rate. We provide experimental

*The experiment reported in this paper was conducted at the economics laboratory of the Universitat Pompeu Fabra (**LeeX**). We would like to thank Carles Perarnau and Estela Hopenhayn for their help in performing the experiments, the Spanish Ministry of Education for its financial support (through a DGYCIT grant), Claudia Olivetti for her research assistance and, of course, the UPF undergraduates who acted as experimental subjects. We acknowledge the comments on earlier drafts of the paper from John Bryant, Jean-Michel Grandmont, Toyomi Ihara, Robert McCleery, Tatsuyoshi Saijo, Kazuo Shimomura, Steve Turnbull and other participants at the Carnegie-Rochester Conference (Pittsburgh, October 1994), the *Colloque: Apprentissage, Coordination at Macroéconomie* (Strasbourg, June 1995), Kobe University's Research Institute for Economics and Business Administration (Kobe, June 1995), Tsukuba University's Economics Workshop (Tokyo, July 1995), and Western Japan Economic Association (Fukuoka, July 1995). We alone are responsible for the paper.

[†]*Correspondence to:* Shyam Sunder, Carnegie Mellon University, Graduate School of Industrial Administration, Pittsburgh, PA 15213; email: sunder@cmu.edu

SSDI 0167-2231(95)00042-X

data to study the conjecture that a "simple" rule, such as a *constant growth of the money supply*, can help coordinate agents' beliefs and help stabilize the economy. Our experimental data provide weak evidence for such a conjecture. The underlying stability parameters of the economy provide a better explanation of observed price volatility than differences in the policy do. In particular, in relatively unstable environments, subjects base their forecasts more on observed fluctuations than on the announcements of stable monetary policies.

1 Introduction

It has been argued that relatively simple rules or policies may promote economic stability because agents can easily learn such rules, making it easier for them to coordinate their beliefs. This, for example, is a concurrent theme in Friedman's [1948] and [1960] proposals for economic stability . There is a basic idea that underlies both proposals: giving primary consideration to long-run objectives, with well-defined rules, will "offer a considerable promise of providing a tolerable degree of short-run economic stability"; in particular, "[the] monetary framework should operate under the 'rule of law' rather than the discretionary authority of administrators [1948]." The two proposals for monetary policy differ. In 1948 Friedman prescribed that "Deficits or surpluses in the government budget would be reflected dollar for dollar in changes in the quantity of money," while in 1960, following the postwar experience, he clearly argued that the Federal Reserve System "should be instructed to keep the rate of growth as steady as it can" (the famous k-percent rule). Even in 1948, however, he had already admitted that "It must be granted, however, that the present proposal is less likely to stimulate such a favorable psychological climate than a **simpler and more easily understood goal**, for example, a proposal which sets a stable price level as its announced goal. *If the business world were sufficiently confident of the ability of the government to achieve the goal*, it would have a strong incentive to behave in such a way as to greatly simplify the government's task" (bold ours; italics Friedman's).

In the last few years, the economics profession has focused on the issue of the *time consistency* problem of acting according the 'rule of law.' In contrast, we focus on the 'learning' aspect described by Friedman: Can relatively simple rules, such as a k-percent rule, help stabilize the economy?

There is a trivial sense in which the answer to the above question can be negative. Consider an environment where there is no confusion, or credibility problem, about how the monetary policy is conducted. If a policy with more instruments is considered more "complex," then, since the monetary policy can always choose not to use some of the instruments, such a policy dominates a (simpler) policy with fewer instruments.[1]

There is another, perhaps not so trivial, sense in which the answer to the above question can be affirmative. Consider an environment where agents face a 'signal extraction problem' regarding the realized monetary policy. Then, a policy with more instruments or contingencies can make the signal extraction task more difficult for the agents, and their confusion may enhance volatility.[2]

We study an environment where the monetary policy is public knowledge and the monetary authority has no informational advantage. Our environment is represented by an overlapping generations (OLG) model in which agents use money as a unique asset to transfer wealth across the two periods in which they are active. We compare the effect of alternative (single instrument) policies on price volatility. The government can either fix the level of real deficit and finance it through seigniorage (*deficit rule*) or fix the rate of growth of the money supply (*money-growth rule*) and adjust the level of public expenditures financed through seigniorage as to satisfy the monetary target. Under the first policy the rate of growth of the money supply is endogenous, while the level of (real) seigniorage is predetermined (fixed) (and presumably consumed by the government). Under the second policy the rate of growth of the money supply is predetermined (fixed), while the level of (real) seigniorage is endogenous. Notice that both regimes correspond to different fiscal environments, although they may be equivalent at the steady state. We are not interested in studying different monetary-fiscal policies, that, for example, raise the same government revenue. We are interested in studying different regimes that share similar rational expectations equilibrium properties, but may have different empirical properties in environments where agents do not have *common knowledge* about these equilibria. In particular, we identify the second policy regime with Friedman's proposal for a stable growth of money supply, and we identify "Friedman's conjecture" with the hypothesis that the *money-growth rule* results in a more stable behavior of prices (inflation rates).

The environment that we study has a well-known indeterminacy problem: under any policy, there is a continuum of nonstationary rational expectations equilibria (REE). While the problem itself has been studied by

[1]A similar argument can be used to address the welfare properties of different policy regimes. For example, Sargent and Wallace [1982] have shown that in a relatively simple environment with legal restrictions, an active discount window policy that they associate with the *real bills doctrine*, can result in a better equilibrium outcome (in terms of welfare, but not price stability) than a simple *quantity theory* prescription which, as Friedman [1960] suggests, keeps the discount window closed.

[2]The well-known Lucas [1972] model provides an environment with a 'signal extraction problem' where Friedman's k-percent rule results in a Pareto-optimal equilibrium allocation.

Woodford [1986] and others, less attention has been paid to its empirical relevance. Given the difficulty of conducting relevant experiments in the field, experimental setting holds promise of casting light on the empirical aspects of this problem. By controlling the parameters of the laboratory economy, it is possible to identify the relation between observed paths and the set of theoretical equilibria. Given the focus of this conference (volume) on indeterminacy problems, a summary of our prior work on this topic is in order.[3]

In Marimon and Sunder [1993] we examined a laboratory monetary economy characterized by a constant level of deficit financed through seigniorage.[4] Our data are not consistent with nonstationary REE; inflation paths tend to cluster around one of the two steady-state REEs (the low inflation steady state). That is, the laboratory economies *select* a long-run steady state which is consistent with the selection made by a large class of adaptive learning algorithms. In Marimon, Spear, and Sunder [1993] we studied an economy where there can be REE with fluctuations determined by extrinsic sources of uncertainty or "sunspots." More specifically, we posed the question of whether sunspot equilibria could emerge in an experimental lab economy. That these equilibria could be learned, and therefore could not be ruled out, had been shown by Woodford [1990] and others. From our laboratory data we inferred that emergence of sunspot equilibria is unlikely unless agents learn to predict economic fluctuations while in a real shock regime (where sunspot shocks are correlated with real shocks.) That is, after a real source of uncertainty disappears, agents' behavior may show enough persistence as to sustain the sunspot fluctuations. When these conditions were created in laboratory, we occasionally observed persistence of sunspot-like fluctuations.

In Marimon and Sunder (1994) we studied whether our previous "selection" results are robust to different policy specifications. In that paper, we also analyzed agents' behavior before and after the time of preannounced policy changes. In this and later experimental work we observe that, after enough experience agents learn to anticipate the effects of preannounced policy changes. *Agents' learning through stationary environments* is a common observation in all our experiments independent of whether the environment consists of a fixed policy regime, a (real) cycle, or a systematic change of policy. Furthermore, and since agents share a common experience, their learned patterns may *feed back* into the economy. In the standard OLG model with seigniorage, this implies convergence to the low inflation steady state; in the

[3] See Sargent [1993] for further references on related experimental and simulation work.

[4] Our experimental economies have some natural departures from the theoretical model under study (see Section 3). In Marimon and Sunder [1993] we also analyze the explicit game that takes place in our experimental lab. In particular, we show that, as much as there is a competitive outcome within generations (and we have at least five subjects per generation), the set of Nash equilibria of the game contains all rational expectations equilibria of the underlying model.

economy with 'sunspots,' this implies the possible persistence of *belief-driven* cycles; in the environment with repeated preannounced policy changes, this implies the existence of a (rational expectations) anticipation effect. We have never observed long, much less infinite horizon, anticipation effects, as postulated in nonstationary REE equilibrium paths.

For the monetary authority to know that nonstationary REE paths are unlikely, or that 'purely belief-driven' equilibrium fluctuations are also unlikely, implies that the policy debate can be more conclusive. For example, one can have more solid grounds to argue for the 'classical prescription' that a reduction of the deficit financed through seigniorage should translate into a lower inflation rate. But 'the broad convergence picture' or 'long-run' statements may be of limited interest for actual policy implementation. The concern for price stability is rooted not in the possibility of exceptional episodes of hyperinflation but in the short-run volatility of the price of money and other assets that most economies experience. To address this issue, one must ask questions about how the design of economic policies may affect local stability properties. This is the aim of this paper.

We ask a specific question: Does a (simple) constant money growth rule help stabilize prices (inflation rates)? We compare it with a less transparent, or more complex, rule of maintaining a fixed level of real deficit.[5] We design an experimental environment to address this issue. Of course, the question we address is an instance of the broader issue of *rational expectations equilibria* and *learning behavior* in economies that present persistent short-run fluctuations.

Our experimental economies have all the features that favor Friedman's conjecture about long-run objectives providing short-run stability. First, if a μ-percent *money-growth rule* is announced, then for a broad class of agents' learning rules, inflation rates converge to the announced rate (i.e., $\pi_t \longrightarrow \mu$). That is, the policy announcement is a public announcement about "fundamentals" that determine the long-run steady state. Second, if agents believe that the announced money-growth rate will be the realized inflation rate (in our OLG model, for the next two periods), then the realized inflation rate *is* the announced money-growth rate. That is, the long-run equilibrium can be achieved in the short-run if agents' predictions coincide with the policy announcement.

The actual dynamics of an economy is a more complex combination of agents' behavior (because they may not take the announcements at their face

[5]Notice that we do not explicitly address the question of what it means for a rule to be 'complex.' There is, however, a well-defined sense in our experiments by which a 'less transparent rule' is considered a 'more complex' rule when both support the same type of equilibrium allocations. Other authors have identified simplicity with dimensionality of the rule (see, for example, Currie and Levine [1993]).

value) and the underlying stability properties (nonlinearities) of the economy.

Suppose a rational agent perfectly understands the above two statements, that is: *(i)* what *should* happen in the long-run and, *(ii)* what *should* happen if everyone understands and believes (i.e., it is *common knowledge*) that the announced money-growth rate will be the future inflation rate. If this agent is placed in an economy where, in spite of policy statements, price volatility persists, or perhaps follows some cycle, then the expected returns of his savings will not depend on what *should* happen; they will depend on what actually happens. A rational agent may not close his eyes to what he actually sees happening. But then, he and others may optimally choose actions that deviate from actions in the long run steady state. These deviations may slow down, or may even prevent, convergence of inflation to the announced target rate of money growth. The force of Friedman's, and other similar, recommendations in coordinating beliefs may be lost by *day-to-day* behavior.

It may still be true that realized inflation is *on average* very close to the announced money growth target. The question is: Do agents base their forecasts on this average inflation? It does not seem this way in our experimental data. It may be argued that it is because in our OLG economies, agents are "short-lived" and there are not enough financial instruments to hedge against persistent fluctuations. However, if agents cannot *ex ante* insure against all possible fluctuations, then even with "longer lives" and a more developed financial structure price fluctuations may persist: after an observed common experience, relatively impatient agents may have similar forecasts for (short-run) future fluctuations and they may all want to trade in the same direction.

While the issues discussed here are not new, to our knowledge, we are the first to provide data that may help enhance our understanding of their relevance. Our experimental data show clearly the above-mentioned interaction between the learning process and the underlying nonlinearities of the system. That is, there are two dimensions to the problem under consideration. One is whether a *deficit rule* or a *money-growth rule* is pursued; the other is the underlying local stability properties of the stationary equilibrium.

Our subjects did not know the specific OLG model we implemented in laboratory, but there is clear evidence that at least some of them took the announcement of a *money-growth rule* into consideration when making their forecasts. However, when the economy is not very stable (for example, when eigenvalues, of the underlying map relating inflation expectations and realized inflations, are inside the unit circle, but relatively close to one), the announcement of a target money-growth rate does not have the effect of helping agents coordinate their beliefs. On the other hand, in relatively stable environments, even if the chosen policy is the less transparent (and more complex) *deficit rule*, coordination of beliefs emerges through agents' experience.

In summary, while we find some weak evidence for Friedman's conjecture, our data show that the underlying stability properties of a stationary equilibrium can be a more decisive factor for price stability than the actual policy design; in relatively unstable environments, the fact that the policy target identifies a stationary rational expectations equilibrium may have little effect on coordination of agents' beliefs. That is, primary policy consideration of long-run objectives may *not* translate into short-run economic stability.

2 Monetary policies in OLG models

We study an economy with an OLG structure in which fiat money is the only financial asset. We consider two alternative policy regimes. In one, called the *deficit rule*, the government fixes a constant level of real deficit financed through seigniorage. Government expenditures do not enter into agents' utilities. This model is a version of Cagan's model of hyperinflation [1956] and has been previously studied, among others, by Sargent and Wallace [1987] and in our own experimental work (Marimon and Sunder [1993] and [1994]). In the other policy regime (we call it the *money-growth rule*) the government fixes the rate of growth of the money supply and adjusts the level of seigniorage as to satisfy its money growth rule. This model is a version of Friedman's rule of a "constant growth of the money supply." In our version of the model, the seigniorage proceeds are not returned to the consumers. Therefore, it can be thought as if the government finances some residual expenditures. That is, the stability of the monetary policy may result in volatility of the government expenditures.

Each generation has n agents, and generations born after period zero live for two periods. An agent i of generation t, t=1,..., has a two-period endowment of a unique perishable good $(\omega^1_{t,i}, \omega^2_{t,i}) = (\omega^1, \omega^2)$, $\omega^1 > \omega^2 > 0$, and his preferences over consumption are represented by $u_i(c^1_t, c^2_t) = \ln(c^1) + \ln(c^2)$ where the superscript denotes the period in the agent's life. An agent i of the initial generation that exits in Period 1 only lives for one period, and is endowed with $\omega_{0,i} = \omega^2$ of the consumption good. He also has an endowment of fiat money of h_0 and his preferences are represented by $u_i(c_0) = \ln(c_0)$.

Given a sequence of consumption good prices $\{p_t\}_{t=0}^{\infty}$, an agent i of generation $t, t \geq 1$, solves the problem,

$$\begin{aligned} &\max\ \ln c^1_t + \ln c^2_t \\ \text{s.t.}\quad &p_t(c^1_t - \omega^1) + p_{t+1}(c^2_t - \omega^2) \leq 0. \end{aligned}$$

Let $\pi_{t+1} = p_{t+1}/p_t$, and $\pi^e_{t+1} = \mathbf{E}_{t-1}\pi_{t+1}$ (i.e., expectation at the beginning of period t about the rate of inflation between periods t and $t+1$). If $\omega^1 - \omega^2$

is large enough, the agent's saving in the first period of his life is

$$s_t = 0.5(\omega^1 - \pi^e_{t+1}\omega^2). \tag{1}$$

Let h_t be the *per capita* money supply in period t. To study both policy regimes together, we consider that the government either finances a constant per capita level of deficit d through seigniorage, or allows money to grow by a factor of μ. The supply of money follows the process

$$h_t = h_{t-1} + p_t d,$$

when a fixed d is financed, and

$$h_t = \mu h_{t-1}$$

when a fixed money (gross) growth rate $\mu = (1+g)$ is the target, which results in financing the residual expenditures,

$$r_t = (h_t - h_{t-1})/p_t = g h_{t-1}/p_t.$$

That is, by setting $\mu = 1$ when $d \neq 0$ and $d = 0$ when $\mu \neq 1$, the per capita money supply in real terms, $m_t = h_t/p_t$, is given by[6]

$$m_t = \mu m_{t-1}/\pi_t + d. \tag{2}$$

The equilibrium condition is

$$m_t = s_t. \tag{3}$$

Equations (1) - (3) define the equilibrium restrictions of the model. They can be integrated into the equilibrium map

$$\Phi(\pi^e_{t+1}, \pi^e_t, \pi_t) = 0,$$
$$\text{i.e.,} \quad \pi^e_{t+1} - (b - ed) + \mu\frac{b-\pi^e_t}{\pi_t} = 0.$$

where $b = \frac{\omega^1}{\omega^2}$ and $e = \frac{2}{\omega^2}$. Stationary solutions satisfy $\Phi(\bar{\pi}, \bar{\pi}, \bar{\pi}) = 0$ and if $(b - ed + \mu)^2 > 4\mu b$, there are two stationary solutions (π^L, π^H). In the case that $d = 0$ and $\mu > 1$, the two stationary solutions are $\pi^L = \mu$ and $\pi^H = b$. That is, π^H defines a nonmonetary (autarkic) equilibrium.

For $\pi^e_t \neq b$, $\partial_3\Phi(\cdot) = -\mu\frac{b-\pi^e_t}{(\pi_t)^2} \neq 0$,. It follows, by the Implicit Function Theorem that

$$\pi_t - \mu\phi(\pi^e_{t+1}, \pi^e_t) = 0, \tag{4}$$
$$\text{where} \quad \phi(\pi^e_{t+1}, \pi^e_t) = \frac{b - \pi^e_t}{b - \pi^e_{t+1} - ed}.$$

[6]In some of our experimental economies the level of deficit is subject to an almost negligible shock. The extension of our model to include this type of uncertainty is straightforward and it is not included here.

Equation (4) describes the equilibrium dynamics of the economy: actual inflation as a function of expected inflation for the current and the following period. That is, if H is the set of all possible infinite histories of inflation rates, then (4) defines a map from beliefs to realizations, $T : H \mapsto H$. For example, if there is a representative agent with beliefs $\{\pi_t^e\}_{t=0}^{t=\infty}$, then the realized inflation path is given by $\{\pi_t\}_{t=0}^{t=\infty} = T(\{\pi_t^e\}_{t=0}^{t=\infty})$, according to (4). One can close the equilibrium conditions by postulating the *rational expectations hypothesis.* A *rational expectations equilibrium* is a fixed point of T:

$$\pi_t = \pi_t^e. \tag{5}$$

Monetary REE, which satisfy $\pi_t \in (0,\, b)$, are paths satisfying the following difference equation

$$\begin{aligned} \pi_{t+1} &= R_{(\mu,d)}(\pi_t), \\ \text{i.e.,} \qquad \pi_{t+1} &= (b + \mu - ed) - \mu \tfrac{b}{\pi_t}. \end{aligned} \tag{6}$$

Equilibrium paths with $\pi_0 \in (\pi^L,\, \pi^H)$, are characterized in the long run by $\pi_t \to \pi^H$ (exponentially). It should be noted that even if the map $\phi(\cdot,\cdot)$ of (4) has a two dimensional domain, the *rational expectations hypothesis* reduces to one dimension the domain of the $R(\cdot)$ map of (6). Figure 1 shows two $R_{(\mu,d)}(\cdot)$ maps for an economy with a given endowment structure ($b = 6$). The thick line characterizes REE paths with a *money growth rule* ($d = 0$ and $\mu = 2$, i.e., $R_{(2,0)}$), the thin line REE paths with a *deficit rule* ($d = 1$ and $\mu = 1$, i.e., $R_{(1,1)}$).

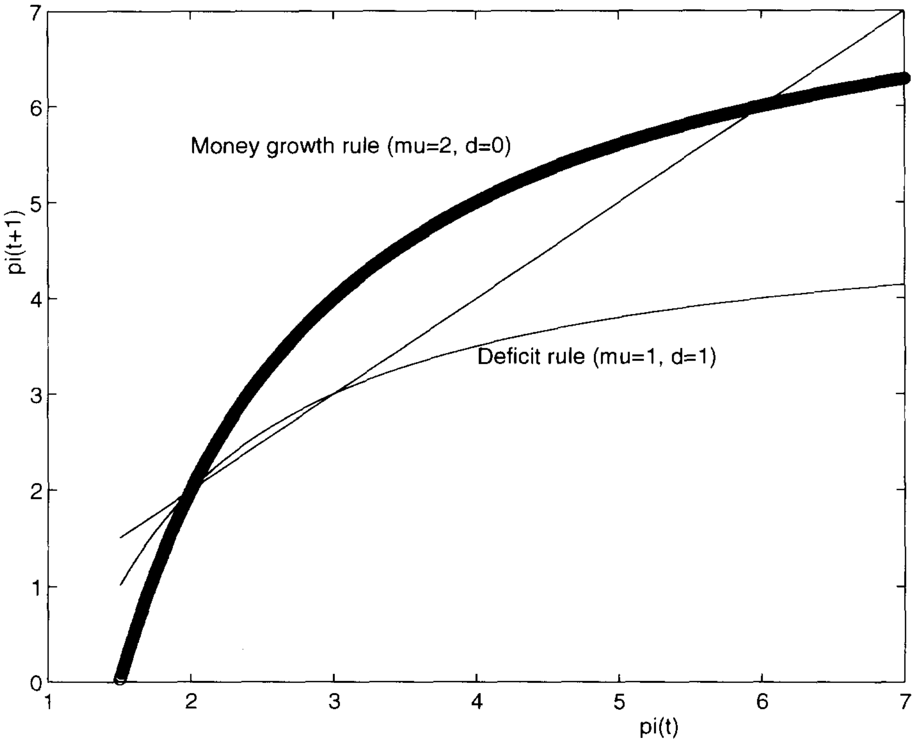
Note that for the *deficit rule* only the Low ISS, π^L, satisfies the "classical" property that a reduction of the deficit financed through seigniorage translates into a lower stationary inflation rate. Similarly, the recommendation to follow a *money growth rule* is meaningless along REE nonstationary paths for which, in the long run, money has no value.

While the theoretical model postulates that under the rational expectations hypothesis there is a continuum of nonstationary REE paths that reach π^H in the long-run, it does not mean that these equilibria are more likely to be observed. A specific perfect foresight equilibrium path presupposes a high degree of coordination among agents' expectations. Adaptive learning theory allows for agents' possible coordination of beliefs to emerge from their common experience. In this case, the actual evolution of the economy –say, of inflation rates– depends not only on the underlying dynamics of the economy defined by (4) but also on agents' learning behavior.

For example, we can consider that agent i forecasts inflation rates using a first-order adaptive scheme. That is,

$$\pi_{i,t+1}^e = \pi_{i,t}^e + \alpha_{i,t}(\pi_{t-1} - \pi_{i,t}^e). \tag{7}$$

Figure 1. R(.) maps (Equation (6); b=6)



This general adaptive scheme encompasses many specific learning algorithms[7]. Least squares learning takes this form with α_t converging to zero at the rate of $1/t$ if agents forecast inflation rates, and α_t converging to a constant, $\alpha \in (0,1)$, if agents forecast prices (see, for example, Marcet and Sargent [1989]). In fact, as Evans, Honkapohja and Marimon, [1995] show, if some legal restriction or convertibility rule prevents the government from exhausting all the savings of the economy with its seigniorage tax, then, for a broad class of learning rules, there is *global* convergence of inflation paths to the Low ISS, π^L. This means that coordination of beliefs –and final fulfillment of expectations– is the result of individual learning in these environments. This class, however, is characterized, among other things, by $\alpha_t \rightarrow (0, \underline{\alpha})$, for some $\underline{\alpha} \in (0, 1)$.

In other words, agents must place enough weight on their accumulated experience and not just react to current events. If agents do not place enough weight on their experience (for example, if they use short memory learning rules) then there may not be local convergence to the Low ISS (see, for example, Grandmont and Laroque [1991] and Barucci and Landi [1994]).

Our previous experimental data support the hypothesis that agents behave adaptively. We should, therefore, study the implications of such behavior in detail. To simplify the analysis, we consider an economy with a representative agent (see, Evans, Honkapohja, and Marimon, [1995] for a version with heterogeneous agents). By incorporating (4) into (7), we obtain,

$$\pi^e_{t+1} = \pi^e_t + \alpha_t\mu_t(\phi(\pi^e_t, \pi^e_{t-1}) - \pi^e_t) \tag{8}$$

We can study the local stability of the above difference equation around the steady state π^*. Let $\hat{\pi}^e_t = \pi^e_t - \pi^*$; then linearizing the corresponding difference equation system at the steady state π^* we obtain

$$\begin{bmatrix} \hat{\pi}^e_{t+1} \\ \hat{\pi}^e_t \end{bmatrix} = \begin{bmatrix} (1-\alpha_t) + \alpha_t\mu\phi_1 & \alpha_t\mu\phi_2 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} \hat{\pi}^e_t \\ \hat{\pi}^e_{t-1} \end{bmatrix}$$

where,

$$\phi_1 = \frac{b-\pi^*}{(b-\pi^*-ed)^2}, \qquad \phi_2 = -\frac{1}{b-\pi^*-ed}.$$

The local stability properties of (8) are characterized by the eigenvalues of the above matrix. Denote by $\lambda(\alpha)$ the vector of eigenvalues, then

$$\begin{aligned} \lambda^1(\alpha)\cdot\lambda^2(\alpha) &= -\alpha\mu\phi_2 \\ \lambda^1(\alpha)+\lambda^2(\alpha) &= (1-\alpha)+\alpha\mu\phi_1. \end{aligned}$$

It follows that

[7] Note that at the time they have to forecast π_{t+1}, agents know π_{t-1} but not π_t.

Proposition 1. Let π^L be well-defined (i.e., let the deficit be sustainable) and let (8) characterize the evolution of expectations. Given a policy characterized by (μ, d) there is a $\underline{\alpha} \in (0,1)$ such that if $\alpha_t \to (0, \underline{\alpha})$, then π^L is locally stable.

If $\lambda(\alpha)$ is a pair of complex eigenvalues, i.e., $\lambda(\alpha) = x \pm yi$, then the law of motion of (8) is characterized by cyclic fluctuations around the steady state π^*. Whether this is stable or not depends on whether $r_{(\mu,d)}(\alpha) = (x^2+y^2)^{1/2}$ is greater than or equal to one (see, for example, Hirsh and Smale [1974]). However, since

$$r_{(\mu,d)}(\alpha) = (-\alpha\mu\phi_2)^{1/2}$$

it follows that the local stability properties are shared by different policies. To see this, consider two economies that differ only in the policy rule. One has a *deficit rule* and the other has a *money-growth rule*, but both have the same Low ISS, $\bar{\pi}$ (in which case, they must have a different High ISS if the deficit rule sustains a positive deficit). For the economy with the *deficit rule*, $(1, d)$,

$$-\alpha\mu\phi_2(\bar{\pi}, \bar{\pi}) = \alpha 1(b - \bar{\pi} - ed)^{-1} = \alpha\frac{\bar{\pi}}{b - \bar{\pi}}$$

The last equality follows from the equilibrium conditions (1) - (3) at the steady state. Similarly, for the economy with the *money growth rule*, $(\bar{\mu}, 0)$,

$$-\alpha\mu\phi_2(\bar{\pi}, \bar{\pi}) = \alpha\bar{\mu}(b - \bar{\pi})^{-1} = \alpha\frac{\bar{\pi}}{b - \bar{\pi}}.$$

The last equality follows from the hypothesis that $\bar{\mu} = \bar{\pi}$. That is, both economies have the same local stability properties around the Low ISS. Formally,

Proposition 2. Let $\bar{\pi}$ be the Low ISS of an economy where the government follows a *deficit rule* $(1, d)$. Suppose $\lambda_{(1,d)}(\alpha)$ is complex. Consider an alternative *money-growth rule*, $(\bar{\mu}, 0)$ for the same economy, with $\bar{\mu} = \bar{\pi}$, then $r_{(1,d)}(\alpha) = r_{(\bar{\mu},0)}(\alpha)$.

The economies we study have the property that $\lambda_{(1,d)}(1)$ is complex. Therefore, if agents make their forecasts based on current observations (which correspond to an α close to one), we should expect fluctuations around the steady state.

Proposition 2 shows that if we detect differences between the two policies, it cannot be due to the fact that the two policies define different stability properties for the evolution of (8). Differences must be due to other factors. For example, if the environment with the *money-growth rule* appears to be more stable, that can provide support to Friedman's conjecture.

3 Design of the experimental environment

We study experimental versions of the overlapping generations (OLG) model with agents who live for two periods (except agents of the first generation who only live for one period), where endowments and preferences are such that agents have an incentive to save, and money is the only financial asset available to save. Alternative monetary regimes differ only in the government's monetary and fiscal policy. Changes in the level of deficit financed through seigniorage and money growth are the only policy instruments considered here. Experimental implementation of the OLG model and the problems associated with it are discussed in Marimon and Sunder (1993, 1994) and are not repeated here. Instructions given to our subjects are included in the appendix to this paper for ready reference.[8]

3.1 *Experimental environment*

Twelve experimental economies, numbered chronologically for reference in this paper, were conducted in five sessions. Table 1 summarizes the parameters of these economies. A fixed number of subjects (N) participate in each session. Subjects know the approximate duration of the session but not of a particular economy. For each period of an economy, agents are assigned specific roles: n subjects act as young consumers, n as old consumers, and the remaining $(N-2n)$ await their turn as interested onlookers in the market. At the beginning of each period, n of the $(N-n)$ players who are not young in the previous period are randomly selected to enter the market. Each player is informed whether he/she enters the market or stays out. Once an agent enters as a young consumer, he/she stays the next period as an old consumer.

Consumers receive a higher endowment of chips (ω^1 units) when young and they may offer to sell some or all of these chips to the old consumers. Young consumers carry the francs (label used for units of fiat money in laboratory) they receive in exchange for the chips to their old age in the next period.

Old consumers add the chips they buy to their endowment of chips $\omega^2 (< \omega^1)$. The number of chips held at the end of the young period, c^1, and at the end of the old period, c^2, a constant and known conversion rate k, determine the cash (in local currency Spanish peseta) amount $k \cdot [\log c^1 + \log c^2]$ earned by the subject when he/she leaves the market at the end of the old period. This cash in pesetas is accumulated across all appearances of the subject in the economy, and the total is paid to him/her at the end of the session.

We have a fixed number of subjects in any given experimental session. A

[8]For design and conduct of economic experiments see Friedman and Sunder (1994) and Kagel and Roth (1995).

Table 1

Parameters of Experimental Economies

Economy	Periods	Agents (N, n)	Endowments (ω^1, ω^2)	h_0	Deficit per capita (d)	Money growth (μ)	Stationary State Equilibria (π^L, π^H)	Eigenvalues at π^L $\lambda(1)$	$\lambda(.5)$	$\lambda(.1)$	Contraction Factor r(1)	r(.5)
T1*	1-5	(14, 6)	(6, 1)	10	0	3.0	(3, 6)	[.5 ± .87i;	.5 ± .5i;	(.89, .11)]	[1	.71]
1	1-48	(14, 6)	(6, 1)	10	1	1.0	(2, 3)	[.5 ± .5i;	(.5, .5);	(.95, .05)]	[.71	-]
T2*	1-4	(14, 6)	(6, 2)	10	0	1.2	(1.2, 3)	[.33 ± .75i;	.42 ± .4i;	(.89, .07)]	[.82	.58]
2A	1-7	(14, 6)	(6, 2)	10	0	2	(2, 3)	[1 ± 1i;	.75 ± .66i;	(.87, .23)]	[1.41	1]
2B	1-16	(14, 6)	(6, 2)	10	0	2	(2, 3)	[1 ± 1i;	.75 ± .66i;	(.87, .23)]	[1.41	1]
2C	1-27	(14, 6)	(6, 2)	10	0	2	(2, 3)	[1 ± 1i;	.75 ± .66i;	(.87, .23)]	[1.41	1]
T3*	1-4	(12, 5)	(6, 2)	10	0	1.2	(1.2, 3)	[.33 ± .75i;	.42 ± .4i;	(.89, .07)]	[.82	.58]
3	1-36	(12, 5)	(6, 2)	10	0	2	(2, 3)	[1 ± 1i;	.75 ± .66i;	(.87, .23)]	[1.41	1]
4	1-21	(12, 5)	(6, 1)	10	0	1.9	(1.9, 6)	[.23 ± .64i;	.36 ± .31i;	(.81, .05)]	[.69	.48]
T4*	1-4	(13, 6)	(6, 1)	10	1	1	(2, 3)	[.5 ± .5i;	(.5, .5);	(.95, .05)]	[.71	-]
5	1-47	(13, 6)	(6, 1)	10	1	1	(2, 3)	[.5 ± .5i;	(.5, .5);	(.95, .05)]	[.71	-]
6	1-6	(13, 6)	(7, 1)	10	1.25	1	(2, 3.5)	[.4 ± .5i;	(.5, .4);	(.94, .04)]	[.63	-]
T5*	1-5	(12, 6)	(8, 1)	10	0	3.1	(3.1, 8)	[.32 ± .73i;	.41 ± .39i;	(.89, .07)]	[.80	.36]
7	1-50	(12, 6)	(8, 2)	10	0	2.0	(2, 4)	[.5 ± .87i;	.5 ± .5i;	(.89, .11)]	[1	.71]
8	1-25	(12, 6)	(6, 1)	10	0	1.9	(1.9, 6)	[.23 ± .64i;	.36 ± .31i;	(.81, .05)]	[.69	.48]
9	1-18	(12, 6)	(6, 1)	10	$.17 + \varepsilon_1$(**)	1.0	(1.07, 5.58)	[.12 ± .45i;	.31 ± .12i;	(.9, .02)]	[.47	.33]
T6*	1-3	(14, 7)	(8, 1)	10	0	3.1	(3.1, 8)	(.32 ± .73i;	.41 ± .39i;	(.89, .07)]	[.90	.56]
10	1-50	(14, 6)	(6, 1)	10	$1 + \varepsilon_2$	1.0	(2, 3)	[.5 ± .5i;	(.5, .5);	(.95, .05)]	[.71	-]
11A	1-5	(14, 6)	(7, 1)	10	$1 + \varepsilon_2$	1.0	(1.59, 4.41)	[.23 ± .49i;	.36 ± .11i;	(.91, .03)]	[.54	.38]
11B	1-27	(14, 6)	(7, 1)	10	$1 + \varepsilon_2$	1.0	(1.59, 4.41)	[.23 ± .49i;	.36 ± .11i;	(.91, .03)]	[.54	.38]
12	1-12	(14, 6)	(14, 2)	10	0	5	(5, 7)	[1.25 ± .97i;	.87 ± .70i;	(.86, .29)]	[1.58	1.12]
	13-28				$2.5 \pm \varepsilon_3$	1.0	(2, 3.5)	[.4i ± .49i;	(.5, .4);	(.94, .04)]	[.63	-]

(*) Indicates a training session; (**) ε is a uniform random variable with range $\pm\varepsilon_u$; $\varepsilon_1 = .17 \times 10^{-3}$; $\varepsilon_2 = .001$; $\varepsilon_3 = .25 \times 10^{-3}$.

<u>Note</u>: All these laboratory sessions were conducted at Leex lab of the Universitat Pompeu Fabra, (UPF) Barcelona. Subjects were UPF undergraduates, mostly economic majors (without much knowledge of the OLG model). The dates were as follows: May 24, 93 (T1, 1); May 25, 93 (T2, 2); June 3, 93 (T3, 3, 4); June 11, 93 (T4, 5, 6); July 13, 94 (T5, 7, 8, 9); July 14, 94 (T6, 10, 11, 12). With a few exceptions, each person participated in only one session.

randomly selected subset enters the market in each period and remains in the market for two consecutive periods. When subjects re-enter the market as young in a subsequent generation, they cannot use cash from this account; they re-enter as new subjects. The total number of subjects (N) is chosen to be sufficiently large ($N > 2n$). Our subjects live several "lives" over the many periods of a particular economy. Assets cannot be carried from one "life" to the next but memory and experience obviously are.

3.2 *Subjects' experience with the setting*

Our experimental OLG model is more like an OLG model in which parents are not allowed to bequeath assets to their children, but they may pass on their experience. Marimon and Sunder [1993, Lemma 1] prove that this repeat entry into the experimental economy does not cause a departure from the OLG model; agents behave competitively within each generation as long as there are no further opportunities for strategic behavior.

3.3 *Trading rules*

OLG models are silent on the mechanism used to exchange chips and fiat money between the young and the old. Lim, Prescott, and Sunder [1994] started out using single-unit double auction with the provision that the last transaction of an old subject in any period could be for a fractional unit to enable him or her to use up all the cash for consumption. This mechanism was awkward, slow, and error-prone, with many old subjects carrying money to their "graves." Cash balances left in the hands of the old caused unintended variations in the supply of money in the experimental economy.

In the economies reported here, discreet unit double auction mechanism has been replaced by a new mechanism. The young are asked to submit an inflation forecast $\tilde{\pi}_{t+1} = \tilde{P}_{t+1}/\tilde{P}_t$ at the beginning of period t when the last price observed by the subjects is P_{t-1}. This inflation forecast is used by the computer to calculate the corresponding optimal individual chip supply for individual i: $s_{i,t} = 0.5(\omega^1 - \tilde{\pi}^i_{t+1}\omega^2)$, $s_{i,t} \geq 0$. The individual supplies are summed across young agents in the cohort to determine the economy's chip supply for the period.

All subjects other than the young are also asked to submit an inflation forecast at the same time as the young. These subjects are induced to provide their best point forecast of inflation by a reward that decreases in proportion to the relative forecast error. Thus, the experiment yields a complete set of information forecasts from all participating subjects.

Note that although subjects are always rewarded according to the accuracy of their forecasts, their *loss function* depends on whether they are young or not. Figure A1 (in Appendix II) shows the final payoffs achieved for various forecasts according to whether a subject is young or not.

All the cash balance in the hands of the old is used to construct a hyperbolic chip demand function. In addition, in fixed deficit economies it is *common knowledge* that the experimenter buys $D = n \cdot d$ chips every period at the market clearing price and that, therefore, the amount of money (francs) in circulation grows. This experimenter or "government" demand for chips is added to the demand of the old to arrive at the market demand function. In fixed money-growth economies, the hyperbolic chip demand function is adjusted for growth in the amount of money in circulation.

The computer calculates the market clearing price as the point of intersection between these supply and demand functions. This price is announced and the resulting allocations are communicated to the subjects each period. The history of prices is also displayed on their computer screens.

3.4 *The terminal condition*

The OLG model has an infinite horizon and, in a strict sense, cannot be cast in an experimental environment (see Aliprantis and Plott (1993) for implementation of a finite period special case). The experimenter's choice of a procedure to terminate the economy may affect the set of equilibria. We use a variation of a procedure introduced by Lim, Prescott, and Sunder (1994).

Recall that all subjects have to submit inflation forecasts at the beginning of each period, and these data are sufficient to determine the market-clearing price for the period. As part of the instructions, the subjects are informed that the experimenter may terminate the economy at any time. If period T is to be the last period of the economy, the experimenter will solicit the inflation forecasts at the beginning of period $T + 1$, calculate the market-clearing price for that period, and then announce that period T was the last period of the economy. Any money balances of the subjects who are young in period T are converted into consumption units at the market-clearing price determined for period $T + 1$. Those who enter the economy as the young at the beginning of period $T + 1$ do not engage in any transactions.

In Marimon and Sunder [1993] we have shown that, with a similar terminal condition, the set of Nash equilibria of the dynamic game played in our experimental lab contains all rational expectations equilibria of the underlying model. A straightforward modification of that proof provides the same result for the game with the terminal condition specified here.

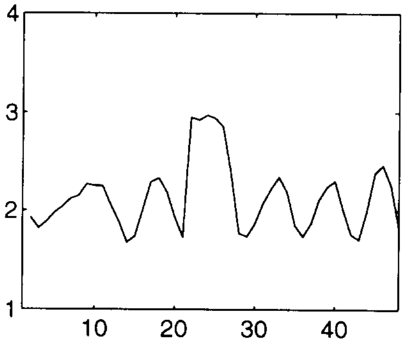
4 *Experimental results*

Table 1 shows some important features of the overlapping generations economies conducted in six separate sessions. In addition to the basic parameters (endowments and government policies) which, in every economy, are public knowledge to all subjects, Table 1 also shows the corresponding stationary equilibria and the local stability properties of the Low ISS. That is, the eigenvalues of the linearized version of (8) at π^L for different values of α, as well as the corresponding contraction factor $r(\alpha)$. In other words, Table 1 shows the two dimensions of the problem under consideration: the policy implemented and the local stability properties of the Low ISS. The economies have been designed to cover a range of parameters and to compare policies across similar economies. For example, Economy 1 and Economy 2 have the same low as well as high ISS, although in terms of its "local stability properties" Economy 1, with a deficit rule, is in-between Economies 7 and 8 (closer to the later) that operate under a money-growth rule.

Figures 2 and 3 show the time series of realized inflation for several economies. Note that economies 1 and 7 show fairly persistent cycles, while economies with a smaller contraction factor show a stronger tendency to converge for both policies. The fact that Economies 4 and 8 show a much stronger tendency to converge than Economy 1, with relatively similar contraction factors, can be used as evidence in favor of Friedman's conjecture. However, Economy 10 –a replica of Economy 1– also shows a relatively strong tendency to converge (with local fluctuations). Figure 3 shows the high volatility of inflation rates in other economies with relatively high eigenvalues.

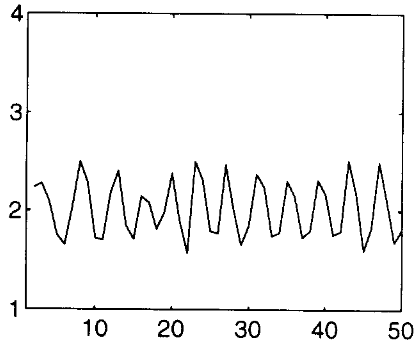
The cycles of Economies 1 and 7 contrast with our previous experimental results where we were actively looking for (sunspot) cycles (see, Marimon, Spear, and Sunder [1993]). In the "sunspot" model, if agents use a second order learning rule (of the form $p^e_{t+2} = p^e_t + \alpha(p_t - p^e_t)$), then adaptive learning converges to a stable two-period cycle. In that experiment, we did our best to obtain such a "sunspot" cycle, but agents tended to use a first-order learning rule (of the form $p^e_{t+1} = p^e_t + \alpha(p_{t-1} - p^e_t)$) and paths tended to converge to the stationary state. Only when agents were subjected to a real cyclical shock that generated a two-period cycle did we observe persistence of the cycle after the real shocks were withdrawn. In that model, the $\phi(\cdot)$ map has a unidimensional domain (it is of the form $p_t = \phi(\pi^e_{t+1})$). In contrast, in the model studied here ϕ has a two-dimensional domain and the local stability properties of the Low ISS are given by a pair of complex eigenvalues; high eigenvalues can result in fluctuations around the steady state. These fluctuations are different from sunspot equilibria because we do not presuppose any coordination of agents' beliefs on a "sunspot" variable.

Fig 2a. Inflation (Eco. 1).



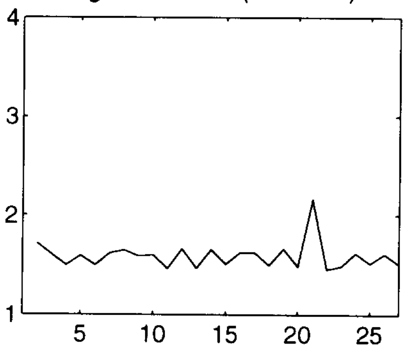
Deficit rule (r(1) = .71).

Fig 2b. Inflation (Eco. 7).



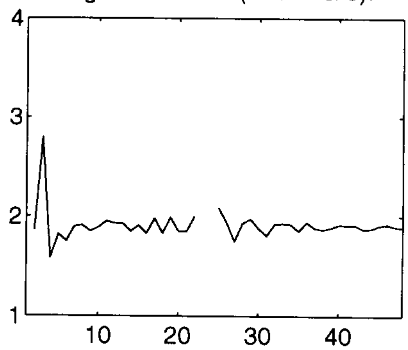
Money growth rule (r(1) = 1).

Fig 2c. Inflation (Eco. 11B).



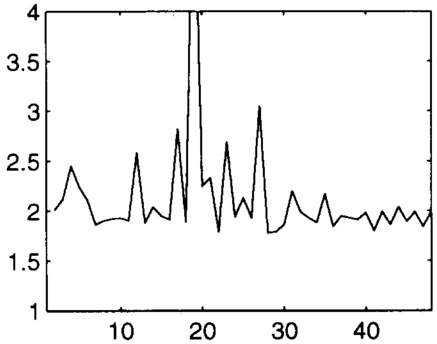
Deficit rule (r(1) = .54).

Fig 2d. Inflation (Eco. 4 & 8).



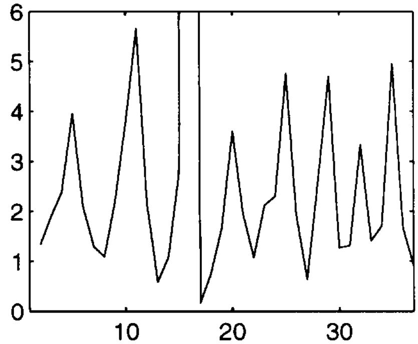
Money growth rule (r(1) = .69).

Fig 3a. Inflation (Eco. 5).



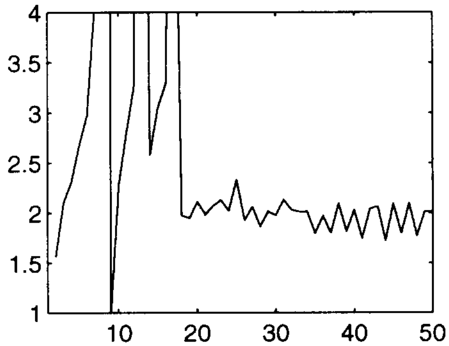
Deficit rule. High eigenvalues.

Fig 3b. Inflation (Eco. 3).



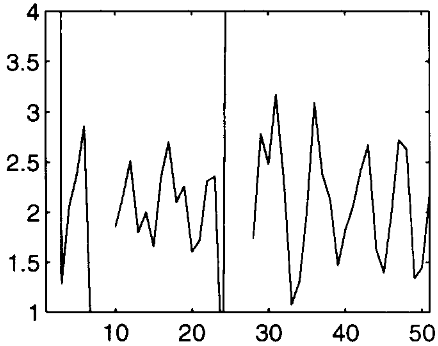
Money growth rule. High eigenvalues.

Fig 3c. Inflation (Eco. 10).



Deficit rule. High eigenvalues.

Fig 3d. Inflation (Ecos. 2A,2B and 2C).



Money growth rule. High eigenvalues.

In fact, in the models considered here there is no stable "sunspot" cycle around the Low ISS (see, for example, Evans and Honkapohja [1993]), and the fluctuations generated by the complex eigenvalues do not define REE paths.

As Table 1 indicates, Economies 1 and 7 have relatively high contraction factors. In particular, for Economy 7: $r(1) = 1$. In fact, if agents follow the forecasting rule with $\alpha = 1$,

$$\pi^e_{t+1} = \pi_{t-1}$$

(8) defines a six period cycle (see, Fig. 7a) for π^e_t, with the corresponding cycle for π_t. One cycle is dephased by two periods so the two coincide. This means that expectations are systematically unfulfilled.

One can also study the existence and stability properties of a k-period cycle –say, 6-cycle– when agents follow a learning rule of the type

$$\pi^e_{t+k} = \pi^e_{i,t} + \alpha_{i,t}(\pi_t - \pi^e_{i,t}).$$

However, for Economy 7 the 6-order learning rule does not define a stable 6-period cycle. A closer look at our experimental data suggests the existence of a 4-period cycle in Economy 7 (see, Fig. 5), but such a cycle is generated neither by a 4-order rule nor by a $\alpha = 1$ rule ($\pi^e_{t+1} = \pi_{t-1}$).

In contrast, the data of Economy 1 suggest the existence of an 8-period cycle (see Fig. 4a). As Fig. 4b shows, once the two-period lag between expectations and realizations is taken into account, the mean prediction tracks the realized inflation remarkably well. This suggests an $\alpha = 1$ rule ($\pi^e_{t+1} = \pi_{t-1}$) for this economy. However, the 8-period cycle generated by such a rule damps down quickly to a constant rate of inflation for Economy 1 (see, Fig. 6a[9])

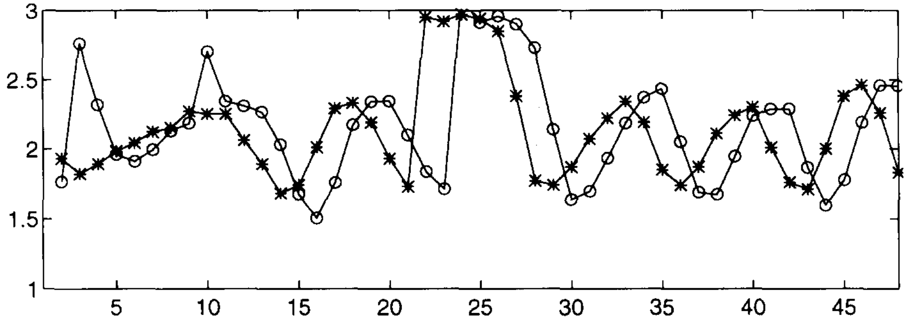
In Tables 2 and 3 we estimate alternative adaptive forecasting rules for individual subjects for Economies 1 and 7, respectively.[10] Table 2 supports the hypothesis of an $\alpha = 1$ rule for Economy 1. For most subjects (10 out of 14) $\alpha \equiv \alpha_1$ is not statistically different from one. For Economy 7 the estimated models do not fit any better than the first-order rules. In particular, 4-order rules do not provide better models than first-order rules. Of particular interest in economies with a *money-growth rule*, such as Economy 7, is the constant coefficient, α_0. If a subject's prediction is the announced money-growth rate, then his prediction should be that constant rate (2 for Economy 7) which should be reflected in the constant coefficient.[11]

[9]The simulations for Fig. 6 and 7 are based on the model $\pi^e_{t+1} = \pi^e_{t+1} + \alpha(\pi_{t-1} - \pi^e_t)$, and the two initial values are taken from the respective realized experimental economies.

[10]All the tables including Estimated Adaptive Forecasting Models are included in Appendix I.

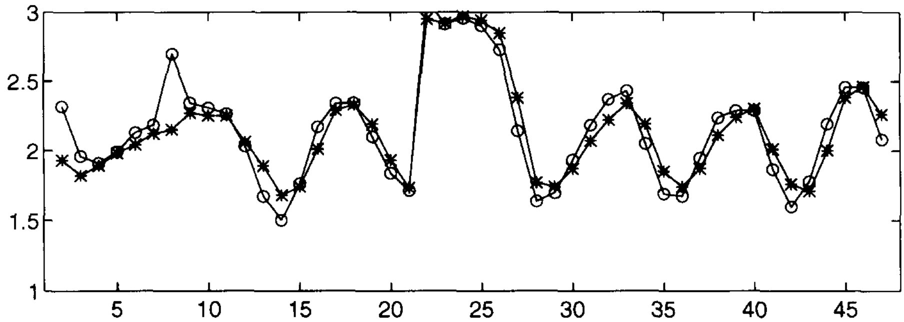
[11]It may also be reflected in its lagged estimate, α_2. A difficulty with these types of estimated models is that they are prone to collinearity problems.

Fig. 4a. Inflation and mean prediction (Eco. 1).



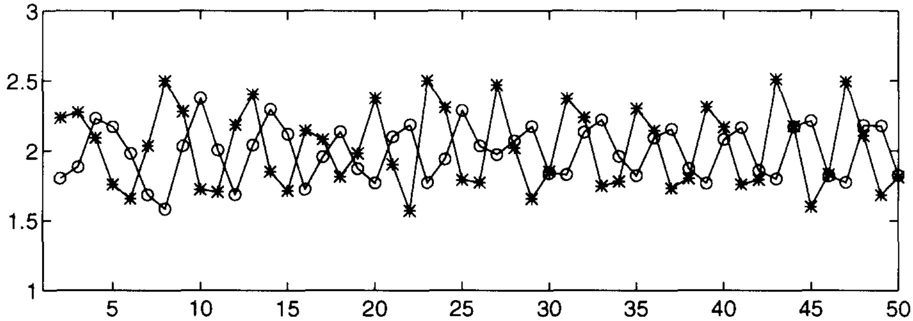
Deficit rule. Inflation(t): * ; mean prediction(t): o

Fig. 4b. Inflation and (shifted) mean prediction (Eco. 1).



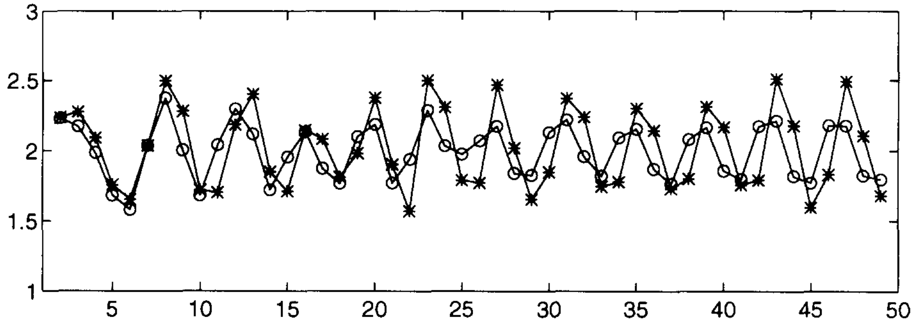
Deficit rule. Inflation(t): * ; mean prediction(t+2): o

Fig. 5a. Inflation and mean prediction (Eco. 7).



Money growth rule. Inflation(t): * ; mean prediction(t): o

Fig. 5b. Inflation and (shifted) mean prediction (Eco. 7).



Money growth rule. Inflation(t): * ; mean prediction(t+2): o

Fig 6a. Simulated Eco. 1.

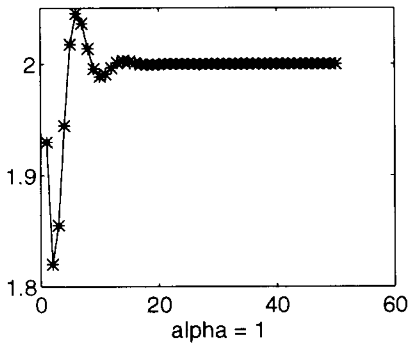


Fig 6b. Simulated Eco. 1.

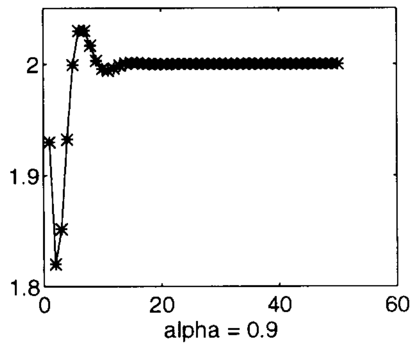


Fig 6c. Simulated Eco. 1.

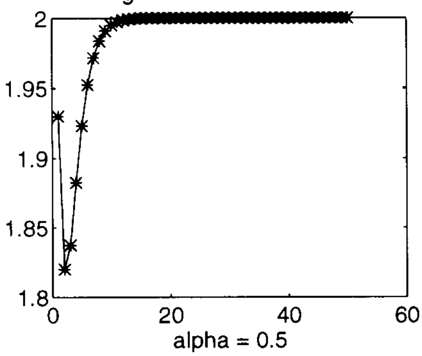


Fig 6d. Simulated Eco. 1.

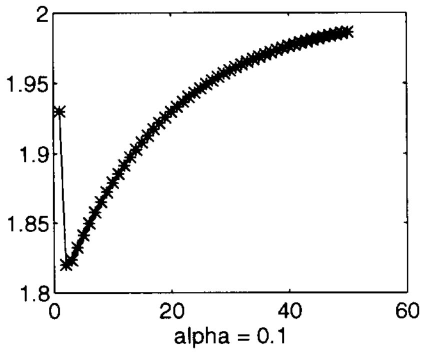


Fig 7a. Simulated Eco. 7.

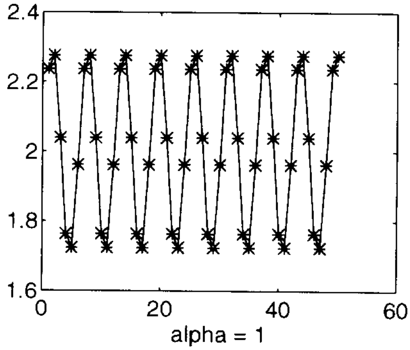


Fig 7b. Simulated Eco. 7.

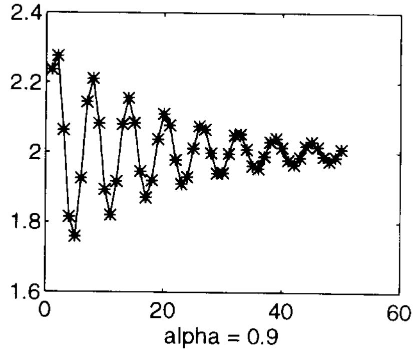


Fig 7c. Simulated Eco. 7.

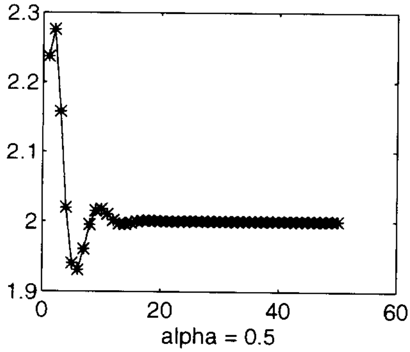
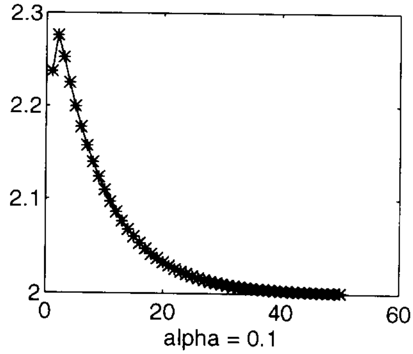


Fig 7d. Simulated Eco. 7.



The fact that the observed forecasting behavior does not fit well with simple adaptive models does not mean that agents are not behaving adaptively. First, the problem of "pattern recognition" in the presence of fluctuations is not a simple one. Agents may take into account such a cyclic pattern in forms that are not captured by simple adaptive forecasting models. Second, the same learning rules may evolve with the specific experience of a given economy, which creates a problem of consistently estimating the learning model.

4.1 *A closer look at Friedman's conjecture*

As we have seen, money-growth rule Economy 7 presents persistent cyclical fluctuations, in the same way that Economy 1, with a *deficit rule*, presents cyclic behavior. Economies with more unstable underlying parameters, such as Economies 2 (A,B, & C) and 3, also show high volatility in spite of the stable monetary policy pursued. This shows that, in these environments, the policy announcement does not help to coordinate beliefs. Agents keep placing enough weight to current, volatile, events that we do not detect convergence to the stationary steady state (αs do not converge to zero!).

As we have noted, Economy 7 is locally more unstable than Economy 1 ($r_7(1) = 1$; $r_1(1) = .71$; see Table 1). Economies 4 and 8 are closer to Economy 1 with respect to their local stability properties ($r_4(1) = r_8(1) = .69$) and as Fig. 2d shows are more stable. While this seems to support Friedman's conjecture, a closer look at these economies does not reveal that agents systematically, and increasingly, use the announced target as their predicted inflation.[12]. Figure 8 shows that the mean prediction for Economy 8 follows a pattern similar to the one observed for Economies 1 and 7.

In Figure 9 we examine the number of subjects who used the announced policy target as their inflation prediction. Although there is evidence that some agents use the announcement as their forecast, we do not observe an increasing coordination of beliefs on the target policy (see Figures 9a-9d). Increasing coordination would have appeared as an upward trend in these scatter charts.

Figures 9e, 9g, and 9i identify the individual subjects in each economy who used the announced rate of money growth as their inflation prediction most often. Figures 9f, 9h, and 9j plot the actual inflation and inflation predictions of these individuals. Even these individuals follow the cyclic

[12]Economies 4 and 8 have 1.9 as target, which may be considered a "more complex" number than 2. However, our subjects had no problem in entering several decimals in their inflation forecasts, and some in fact entered 1.9. It is unfortunate that, at this point, we do not have economies with exactly the same low steady states and local stability properties for both policies. We plan to conduct these experiments in the future, although we think the current economies provide enough information for our purposes.

Fig. 8a. Inflation and mean prediction (Eco. 8).

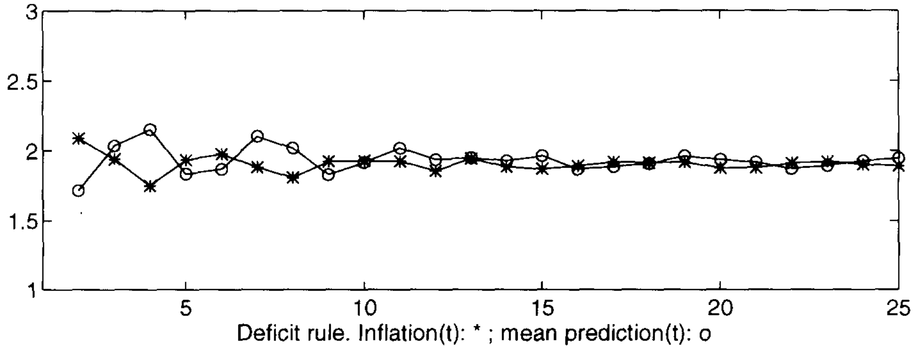
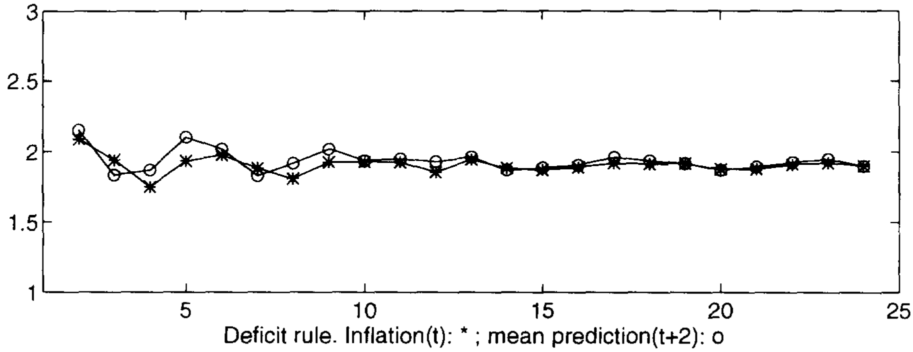


Fig. 8b. Inflation and (shifted) mean prediction (Eco. 8).



behavior of the economy, when fluctuations persist.

Finally, in Figure 10 we show how a change from a *money growth rule* to a *deficit rule* can stabilize the economy when the underlying stability parameters change appropriately. During the first twelve periods, it was a fixed money growth rule economy with a contraction factor $r(1) = 1.58$; from period 13 it was switched to a fixed deficit rule economy with $r(1) = 0.63$. Reduction in the contraction factor seems to have stabilized the economy.

5 Epilogue

The experimental environment developed and studied here is far from capturing the complexity of any historical society; so are the theoretical models. This is the main reason we can learn from both. Nevertheless, our subjects face a fairly complex task of forming expectations about the future behavior of the economy.

While our economic environment is simple (one good and one asset), we also deprive our subjects of possibilities for communication that are routinely available in historical societies: news media, etc. As with other experimental economies, we observe many irrationalities and perturbations in individual data. Nevertheless, even with the small number of agents in each cohort, the aggregate tends to smooth out some, but not all, of these individual variations. One naturally wonders how useful such experimental data can be as a benchmark to improve our understanding of historical economies. One way of answering this question is to see if our laboratory data share some interesting common features with historical economies.

Figure 11 plots the annual Consumer Price Index inflation rate against the rate of growth of money for the U.S. economy (Period 1959-88). We show current and smoothed data.[13] Figure 12 shows our experimental data for Economies 7-12 in a similar (inflation versus money growth) chart. Our economies, based on a deterministic OLG model, give a sharp picture of the quantity theory. For both, the U.S. and the experimental data, we observe fairly scattered data (see Figures 13 and 14, respectively) when we use all the individual observations (in fact, U.S. data are even more scattered) and, at the same time, an almost coincidence of inflation rates and money-growth rates when the data are properly (time) averaged. To the econometrician's eye, the U.S. data and our experimental data might not be qualitatively different. Nevertheless, we know that behind our data there are some clear predictions about which stationary equilibrium is more likely to have been selected and generated the data. Can we say anything about which equilib-

[13] See Lucas [1980] for the smoothing method and its rationale. A 45-degree line has been drawn through the grand mean of all observations in each figure; this is not a fitted line.

Fig. 9a. Eco. 7. "Money growth rule": 2

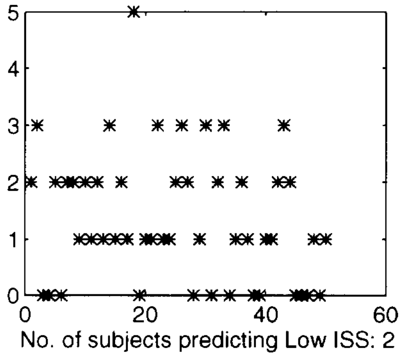


Fig. 9b. Eco. 8. "Money growth rule": 1.9

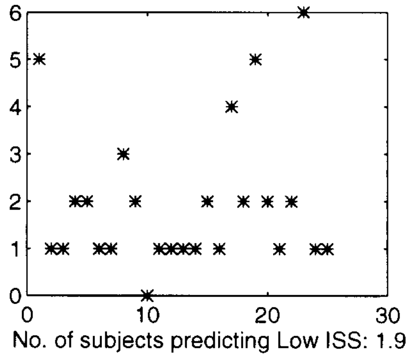


Fig. 9c. Eco. 2A-C. "Money growth rule": 2

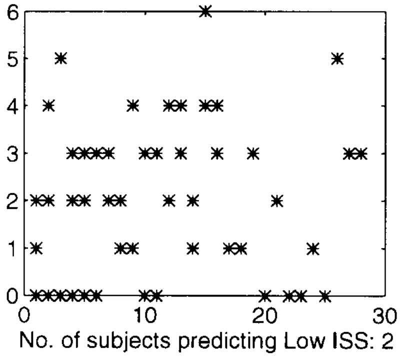


Fig. 9d. Eco. 1. "Deficit rule"

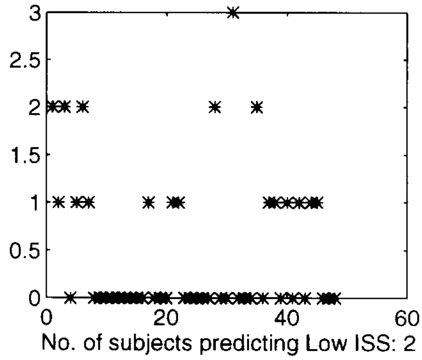


Fig. 9e. Eco. 7. Number of times a subject predicted inflation was the money growth rule "2"

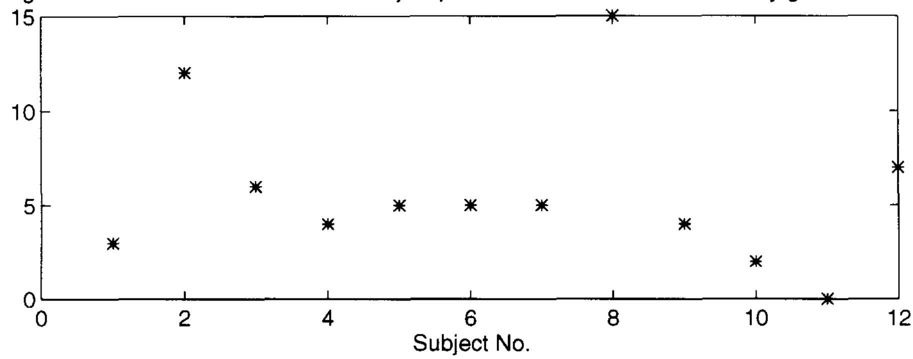


Fig. 9f. Eco 7. Inflation and individual predictions.

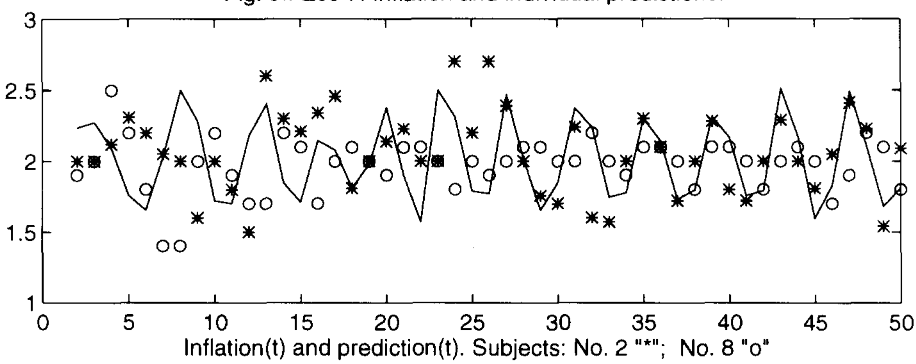
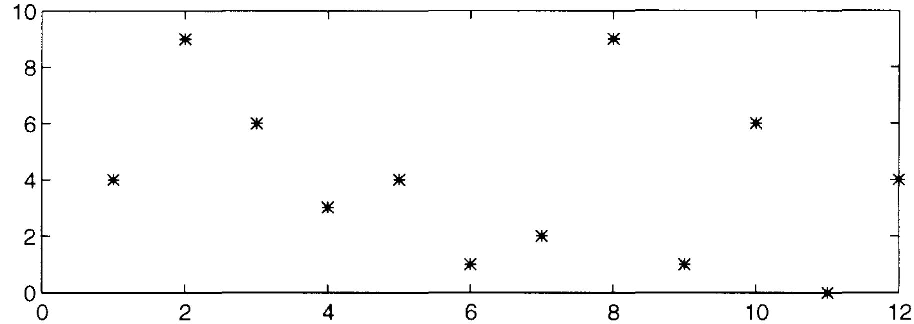
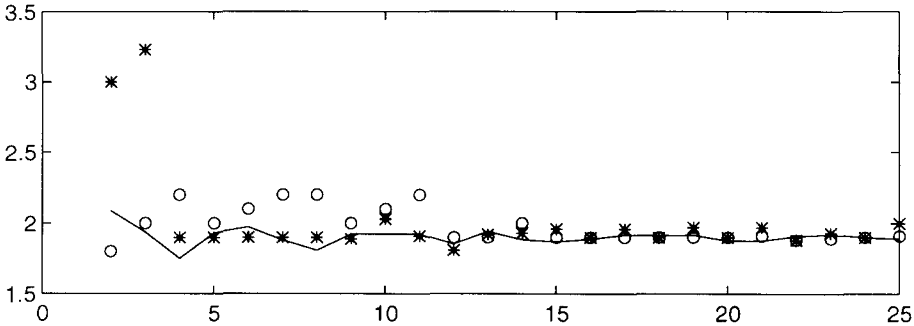


Fig. 9g. Eco. 8. Number of times a subject predicted inflation was the money growth rule "1.9"



Subject No.

Fig. 9h. Eco 8. Inflation and individual predictions.



Inflation(t) and prediction(t). Subjects: No. 2 "*"; No. 8 "o"

Fig. 9i. Eco. 1. Number of times a subject predicted inflation was the Low ISS "2".

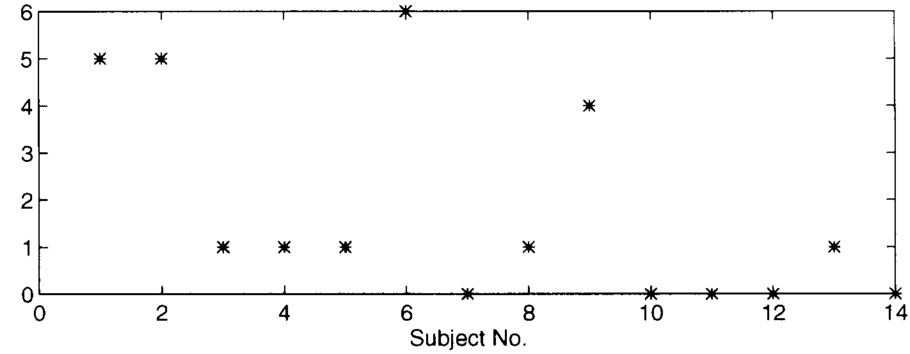
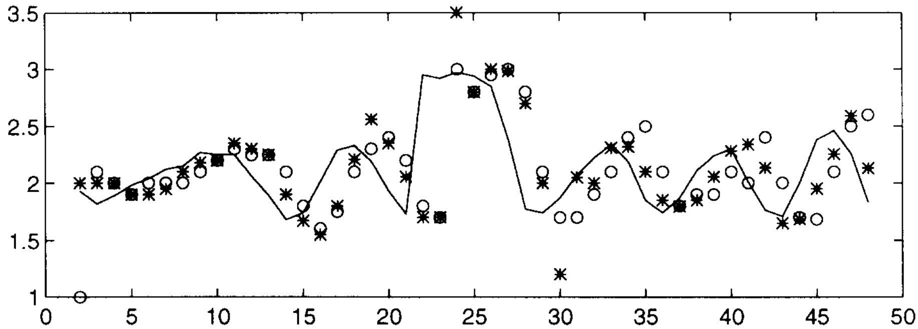
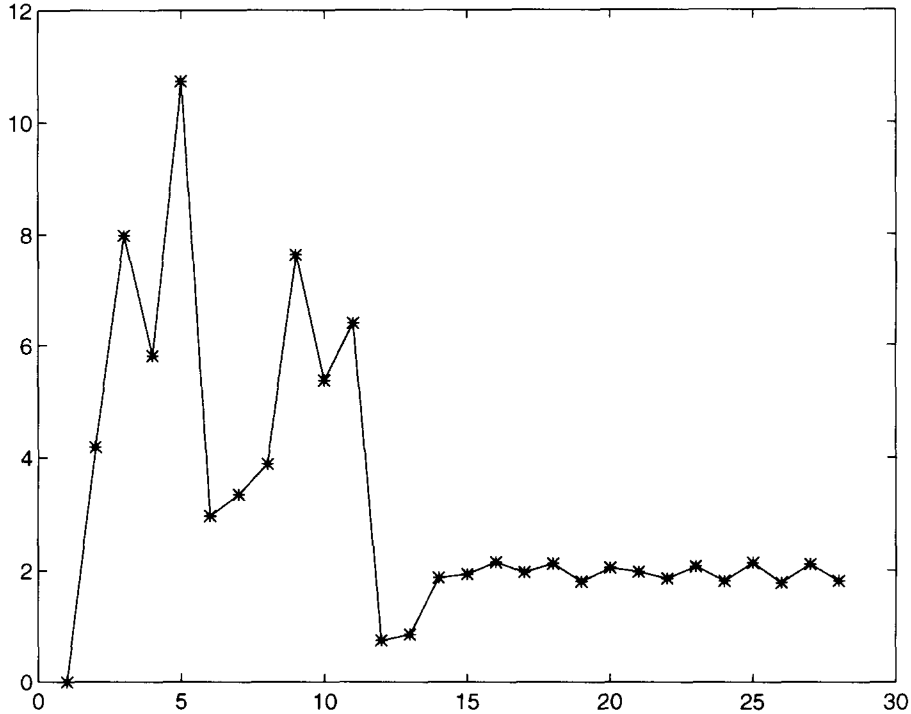


Fig. 9j. Eco 1. Inflation and individual predictions.



Inflation(t) and prediction(t). Subjects: No. 1 "*"; No. 6 "o"

Fig. 10. Inflation in Economy 12

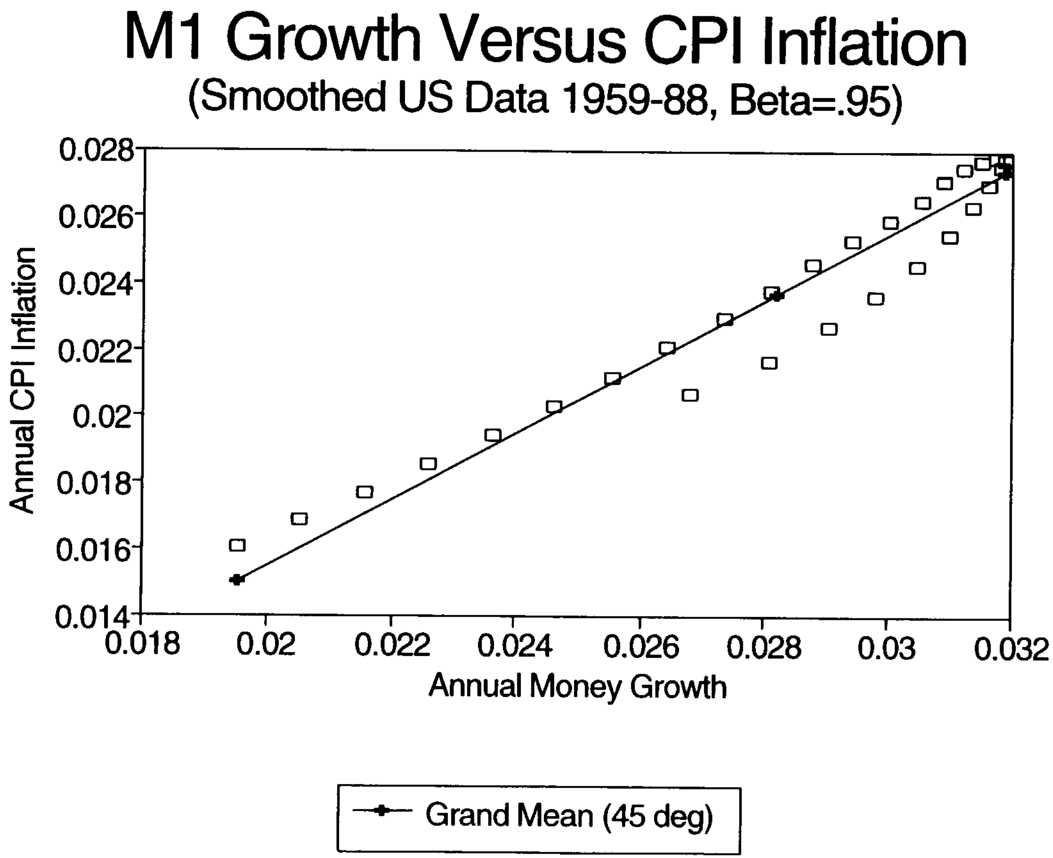


Change from money growth rule (d=0, mu= 5) to deficit rule (d=2.5, mu= 1) in period 13.

rium is more likely to have generated the U.S. (or Argentinean) smoothed data?

We also know that our subjects in the experimental lab closely followed current events in making their *day-to-day* forecasts. In particular, in relatively unstable environments average trends or announced policies play practically no role in agents' forecasts. This reaction to current events *fed back* into the economy and cycling behavior persisted in economies where there are no such equilibrium cycles. As we have seen the experimental smoothed data is even closer to the quantity theory than the actual U.S. smoothed data. However, in our experimental economies we see only weak support for Friedman's conjecture that a policy rule based on long-run objectives, such as a k-percent money-growth rule, can "offer a considerable promise of providing a tolerable degree of short-run economic stability" (Friedman [1948]). The unsmoothed data are more volatile for the U.S. economy than for our experimental economies. What can we say about the validity of Friedman's conjecture with respect to U.S. and other historical economies?

Figure 11



M1 Growth Versus CPI Inflation
(Smoothed US Data 1959-88, Beta=.95)
Annual CPI Inflation
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.018
0.02
0.022
0.024
0.026
0.028
0.03
0.032
Annual Money Growth
Grand Mean (45 deg)

Figure 12

Inflation Versus Money Growth for Economies 7-12 (Smoothed by beta = 0.95)

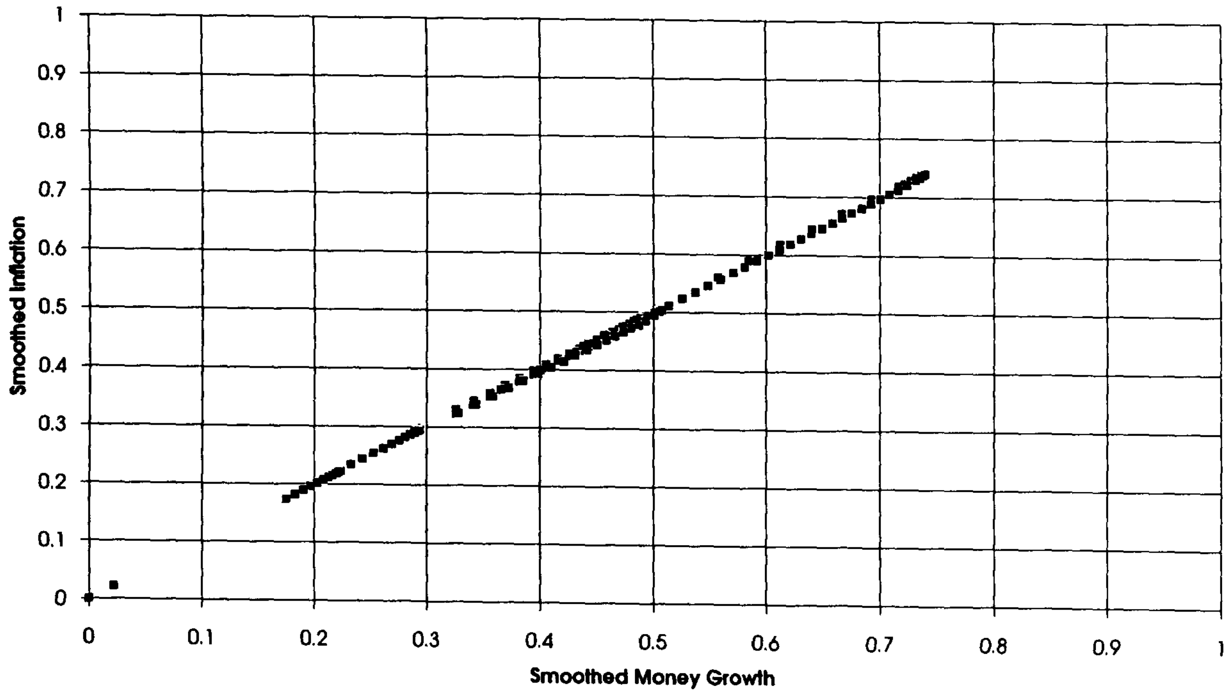


Figure 13

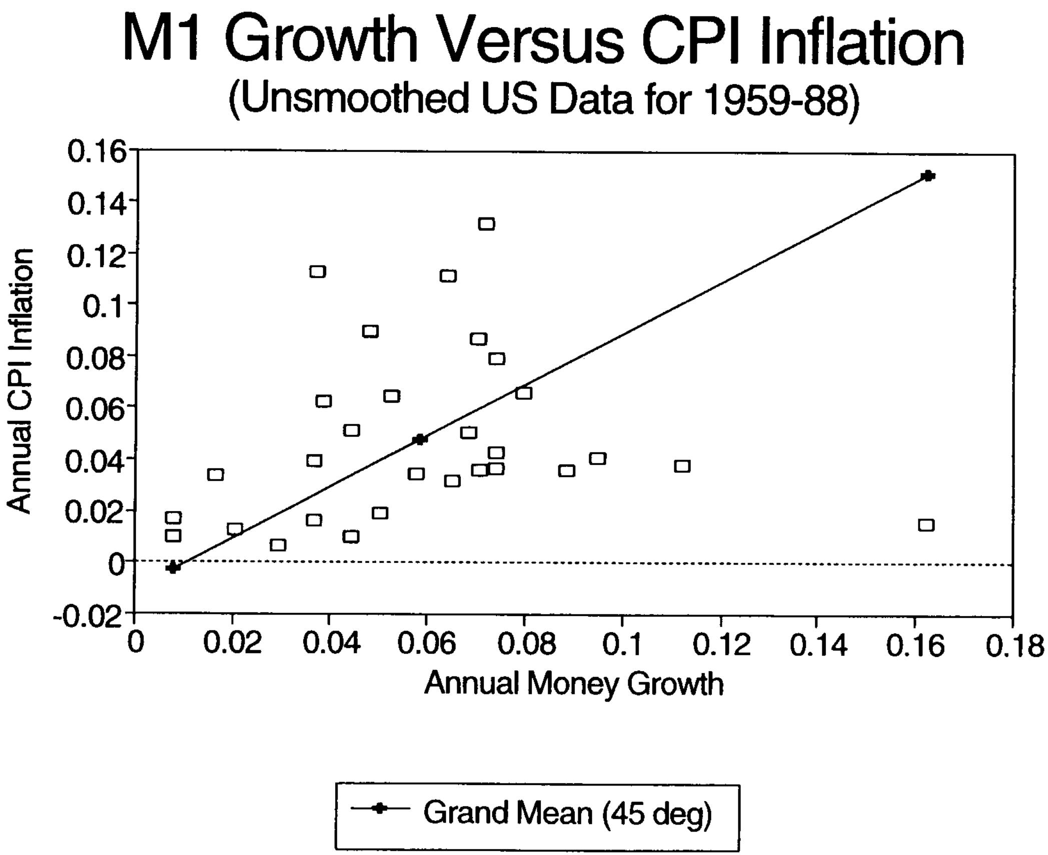
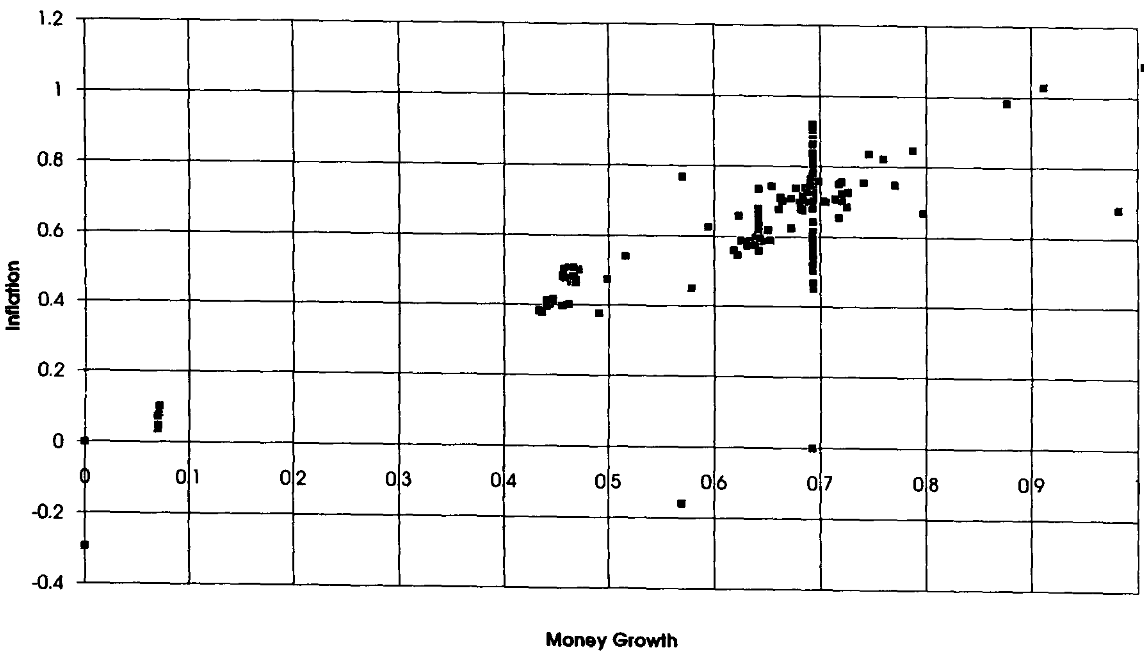

M1 Growth Versus CPI Inflation
(Unsmoothed US Data for 1959-88)
Annual CPI Inflation
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
Annual Money Growth
Grand Mean (45 deg)

Figure 14

Inflation Versus Money Growth for Economies 7-12 (Unsmoothed)



APPENDIX I
Estimated Adaptive Forecasting Models

Table 2
OLS estimates of adaptive forecasting models
Economy 1 (std. dev. in parentheses)

Subj.	$\pi^e_{t+1} = \alpha_0 +$	$\alpha_1 \pi_{t-1} +$	$\alpha_2 \pi^e_t;$	R^2
1	0.01 (0.17)	1.48 (0.13)	-0.49 (0.11)	0.81
2	0.36 (0.18)	0.81 (0.08)	0.02 (0.01)	0.70
3	-0.25 (0.20)	1.00 (0.13)	0.11 (0.10)	0.78
4	-0.27 (0.65)	0.82 (0.32)	0.34 (0.12)	0.34
5	-0.04 (0.19)	0.92 (0.13)	0.09 (0.11)	0.75
6	0.09 (0.09)	1.12 (0.06)	-0.16 (0.05)	0.94
7	0.18 (0.75)	0.99 (0.37)	-0.02 (0.15)	0.16
8	-0.13 (0.08)	1.02 (0.05)	0.03 (0.05)	0.95
9	0.10 (0.26)	0.73 (0.16)	0.20 (0.13)	0.57
10	0.18 (0.27)	0.81 (0.15)	0.12 (0.12)	0.57
11	0.04 (0.16)	1.23 (0.10)	-0.25 (0.09)	0.84
12	-0.14 (0.12)	1.46 (0.08)	-0.41 (0.07)	0.91
13	-0.37 (0.14)	1.17 (0.10)	0.00 (0.07)	0.88
14	0.17 (0.19)	0.86 (0.09)	0.05 (0.02)	0.73

Table 3
OLS estimates of adaptive forecasting models
Economy 7 (std. dev. in parentheses)

Subj.	$\pi^e_{t+1} = \alpha_0 +$	$\alpha_1 \pi_{t-1} +$	$\alpha_2 \pi^e_t;$	R^2
1	1.45 (0.28)	0.48 (0.15)	-0.21 (0.16)	0.20
2	2.57 (0.42)	-0.41 (0.14)	0.17 (0.14)	0.18
3	0.40 (0.27)	0.96 (0.14)	-0.20 (0.12)	0.52
4	1.50 (0.29)	0.57 (0.19)	-0.32 (0.21)	0.17
5	1.22 (0.31)	0.67 (0.16)	-0.28 (0.14)	0.28
6	0.59 (0.22)	0.91 (0.10)	-0.22 (0.09)	0.67
7	0.30 (0.25)	0.25 (0.09)	0.53 (0.11)	0.42
8	1.30 (0.29)	0.14 (0.11)	0.20 (0.16)	0.12
9	0.72 (0.31)	1.14 (0.19)	-0.55 (0.14)	0.45
10	1.16 (0.26)	0.95 (0.15)	-0.56 (0.13)	0.49
11	1.25 (0.32)	0.20 (0.14)	0.16 (0.14)	0.10
12	0.58 (0.49)	0.55 (0.23)	0.27 (0.13)	0.23

APPENDIX II

A Brief Description of an Experiment

These experiments were conducted on student subjects at the Universitat Pompeu Fabra in Barcelona. $N \geq 2n$ subjects were recruited for each session. Of these, n subjects each played the role of "young" and "old" generations, respectively, in any given period, while the remaining $N - 2n$ subjects waited as interested onlookers. At the beginning of each period, n subjects were randomly picked from the group of those who were not young in the preceding period, and the remaining $N - 2n$ were left in the waiting pool. This process ensured that every subject had to wait a random number of periods (minimum 0) between exiting the economy and reentering it as young again.

After reading and explaining the instructions (instructions for Economy 1 follow this narrative), the subjects participated in 5-6 periods of a trial economy. Fiat money was labeled "francs" and the consumption good was labeled "chips." The number of chips "consumed" were converted into Spanish pesetas at the end of the exit period of each subject. Total pesetas accumulated in this manner were paid to subjects at the end of the session in cash. Most sessions lasted for about three hours, and each subject took home 2,000-3,000 pesetas on average from each session.

All subjects were asked to predict inflation in the price of chips, $\tilde{\pi}_{t+1} = \tilde{P}_{t+1}/\tilde{P}_t$ at the beginning of each period t.

From individual inflation forecasts, the computer constructed an optimal market supply for each individual, and a market supply from the individual supply. The computer also calculated a market-demand function for chips from the money balances of the old after considering the government policy on fiscal deficit or money growth. The computer calculated the market clearing price and allocations and distributed this information to all subjects. When the experimenter terminated an economy without advance warning, franc balances of the young in the last period were converted into chips at the market-clearing price calculated for the following (nonplayed) period, before the announcement of termination was made.

Instructions

This is an experiment in decision-making. The Ministry of Education of Spain has provided funds for this research. The instructions are simple, follow them carefully. The money you earn depends on the decisions you and others make. You will make decisions with the help of the computer. This money will be paid to you in cash at the end of the experiment.

This experiment is divided into many periods. Your role may change from period to period. You will have the opportunity to buy "chips," sell "chips," and make predictions of what will happen in the future. The attached Information and Record Sheet will help you keep a record of your decisions and determine their value to you.

The type of currency used in this market is francs. The only use of this currency is to buy and sell chips. It has no other use. The money you take home is in pesetas. The procedures for determining the number of pesetas you take home with you is explained later in these instructions.

You will participate in a market for two consecutive periods at a time. Let us call the first of these periods your *entry* period (because you begin your participation in them), and the second your *exit* period (because you end your participation in the market). Different individuals may have different entry and exit periods. We shall tell you when you *enter* and *exit* the market. You may enter and exit more than once depending on the number of periods for which the market is operated.

Trading and Recording Rules

(1) All entry-period players are sellers and all exit-period players (and possibly the experimenter) are buyers. At the beginning of the entry or exit period you will receive an amount of chips (endowment). This endowment will be always greater in your entry period (young) than your exit period (old). You cannot carry the chips from one period to the next.

(2) Every exit-period player (old) pays all his francs to entry-period players (young) in exchange for chips at a market price determined in the manner explained below.

(3) At the beginning of each period, *every* player (young, old, and outsider) must state the prediction of price ratio for the following period ($\tilde{P}_{t+1}/\tilde{P}_t$) = (1 + inflation rate). Predictions of the entry players (young) will be used to determine the number of chips they wish to sell according to the formula given later on.

(4) After considering the francs available from the exit players (old), offers made by entry players (young) and experimenter's policy (government) about financing the debt with francs and/or incrementing the quantity of francs in circulation, the market-clearing price is computed and announced. Exit players (old) and the experimenter pay this price for each chip they buy. Each entry player (young) will be informed of the number of chips he/she has been able to sell at the market price, and each exit-period player (old) will be told of the number of chips that he/she has been able to buy with his/her francs on hand.

(5) Each exit (old) and outside player receives a reward one period later, depending on how close his/her prediction of price ratio is to the actually observed price ratio. At the end of that period, the experimenter announces the most accurate, predicted price ratio and the market price ratio.

(6) After transaction information is received, through the computer, each

entry player (young) can compute the chips remaining on hand (consume). The francs received from sale will be used to buy chips in the exit period which follows immediately. You can carry your francs on hand forward to the exit period by entering them in the column Francs in the Record Sheet.

(7) Each exit player (old) records the number of chips purchased on the Information and Record Sheet. Then the experimenter computes the pesetas earned by using formula (1) or (1') given below. This amount is the profit of they exit-period player (old) who records this profit on the Information and Record Sheet. At the end, the experimenter will pay each player the total amount of profits in pesetas.

(8) The experimenter may terminate the market at any time. Without any announcement in advance, the participants will be informed which is the last period of the experiment; francs held by all entry-period players (young) are converted into chips using the market-clearing price of the following period.

(9) At the end of the experiment, add up the earnings and prediction rewards columns of your Information and Record Sheet. The experimenter will pay you the sum of these (your cumulative earnings) in pesetas.

Payoffs

The number of "pesetas" you will earn to take home with you for any pair of entry-exit periods will be:

$$\max\{0, e(\log c_1 + \log c_2)\} \tag{1}$$

where e, the exchange rate of "utility to pesetas," is set to 11 pts/chip today.

This means that the greater the product of chips you consume at the end of your entry and exit periods, the greater the number of pesetas you earn to take home with you.

The first period of the market will be an entry period for some of you (as described above). For some of you, however, this first period itself will be an exit period and you will receive the exit period endowment (ω^2). In addition, each of you for whom the first period is an exit period will receive an amount of francs from the experimenter at the beginning of this period. These participants have to use all these francs to buy chips during the exit period because the francs you hold at the end of an exit period are worthless; they cannot be converted into pesetas directly. The payoff of such individuals at the end of Period 1 will be:

$$e(\log c_2) \tag{1'}$$

At the beginning of each period, all of you will be asked to predict the price ratio of chips for the next period. For example at the beginning of

Period 1, you will be asked what will be the ratio of the price of chips in Period 2 to the price of chips in Period 1 ($\tilde{P}_2/\tilde{P}_1$). Please note that at the time you are asked to predict their ratio, you do not know either of the two prices, and, for example, if the price ratio (now) is 1.10, this means that the inflation rate is 10% (the saving nominal interest in francs is 0%).

Automatic "Chip" Supply

If you are in your entry period, the computer will use the price ratio you enter ($\tilde{P}_{t+1}/\tilde{P}_t$) to compute the number of chips you sell in that period, as follows:

$$\max_{0\leq s\leq\omega^1}\{0, \log(\omega^1 - s) + \log(\omega^2 + \frac{s}{\tilde{P}_{t+1}/\tilde{P}_t})\}$$

This means that your optimal decision when you are convinced the price ratio will be $\tilde{P}_{t+1}/\tilde{P}_t$ is:

$$s_{i,t} = 0.5(\omega^1 - (\tilde{P}_{t+1}/\tilde{P}_t)\omega^2) \qquad (2)$$

Notice that the higher the price ratio you enter, the fewer the number of chips you will sell. If your price ratio prediction is ω^1/ω^2 or higher, you will sell 0 (zero) chips.

Predictions Rewards

The price ratio predicted by the exit and outside players will earn them a reward. The more accurate your prediction, the greater the reward (determined by their absolute magnitude of relative error in your prediction):

$$\max\left\{0, e_2\left(1 - \mid\left[\frac{(P_{t+1}/P_t) - (\tilde{P}_{t+1}/\tilde{P}_t)}{(P_{t+1}/P_t)}\right]\mid\right)\right\} \qquad (3)$$

where ($\tilde{P}_{t+1}/\tilde{P}_t$) is your prediction. Today $e_2 = 20$.

This means that the exact prediction will earn you 10 pesetas, and prediction error will reduce your reward proportionately until it becomes zero (0) for an error of 100% or more. Your prediction reward cannot be negative. Entry players will not participate in this prediction reward.

End of instructions

Figure A1 (not displayed to the subjects) shows the different rewards for predictions, depending on whether a subject is young or not. The parameters correspond to the above instructions.

Fig. A1a. Prediction payoffs for a "young" agent.

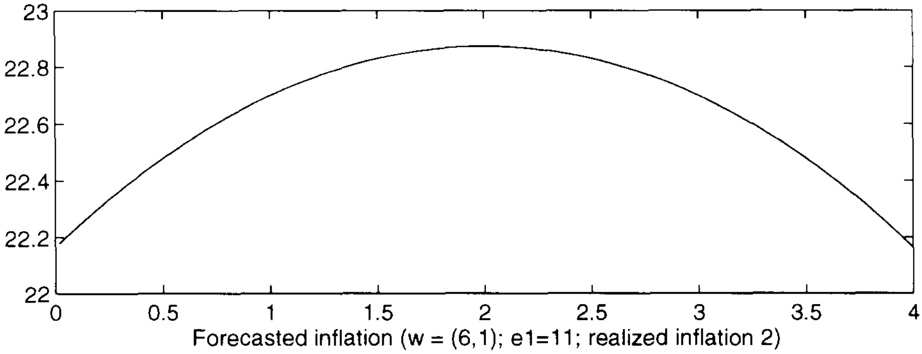
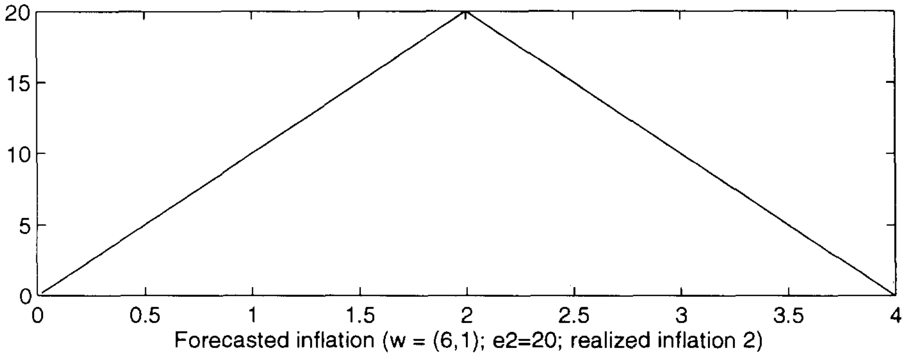


Fig. A1b. Prediction payoffs for an "old" or "outsider" agent.



References

Aliprantis C.D., and Plott, C.R., (1992). Competitive Equilibria in Overlapping Generations Experiments. *Economic Theory* **2**: 389-426.

Azariadis, C., (1981). Self-Fulfilling Prophecies. *Journal of Economic Theory* **25**: 380–396.

Barucci, E. and Landi, L., (1994. Least Mean Squares Learning in Self-Referential Linear Stochastic Models. Mimeo, Università di Firenze.

Bruno, M., (1989). Econometrics and the Design of Economic Reform. *Econometrica* **57(2)**: 275-306.

Cagan, P., (1956). The Monetary Dynamics of Hyperinflation, *Studies in the Quantity Theory of Money*, (ed.) M. Friedman. Chicago: University of Chicago Press.

Chiappori, P.A., Geoffard, P.Y., and Guesnerie, R., (1992). Sunspot Fluctuations Around a Steady State: The Case of Multidimensional, One-Step-Forward-Looking Economic Models, *Econometrica* **60**: 1097–1126.

Currie, D. and Levine, P., (1992). Should Rules be Simple? *Economics of Planning* 25: 113–138. Reprinted in Currie, and Levine (1993): *Rules, Reputation and Macroeconomic Policy Coordination*, Cambridge University Press, Cambridge, UK.

Evans G.W. and Honkapohja, S., (1993). On the Local Stability of Sunspot Equilibria Under Adaptive Learning Rules. Mimeo, University of Helsinki.

Evans G.W. and Honkapohja, S., (1995). Adaptive Learning and Expectational Stability: An Introduction, A. Kirman and M. Salmon (eds.), *Learning and Rationality in Economics*, Oxford: Basil Blackwell.

Evans, G., Honkapohja, S., and Marimon, R., (1995). Global Convergence in Monetary Models with Heterogeneous Learning Rules. Mimeo. European University Institute.

Friedman, D. and Sunder, S., (1994). *Experimental Methods: A Primer for Economists*, Cambridge University Press, New York.

Friedman, M., (1948). Monetary and Fiscal Framework for Economic Stability. *The American Economic Review* **38**: 245–264.

Friedman, M., (1960). *A Program for Monetary Stability.* Fordham University Press, New York.

Friedman, M., (1971). Government Revenue from Inflation. *Journal of Political Economy*, **79**: 846–856.

Grandmont, J.M., and Laroque, G., (1991). Economic Dynamics with Learning: Some Instability Examples, *Equilibrium Theory and Applications, Proceedings of the Sixth International Symposium in Economic Theory and Econometrics*, (ed.) W. A. Barnett *et al.* Cambridge, Cambridge University Press, 247–273.

Guesnerie, R. and Woodford, M., (1991). Endogenous Fluctuations. DELTA Working Paper No. 91-10.

Hirsch, M.W. and S. Smale (1974). *Differential Equations, Dynamical Systems, and Linear Algebra*, Academic Press, San Diego, CA.

Kagel, J. and Roth, A., (1995). *A Handbook of Experimental Economics*, Princeton University Press, Princeton, N.J.

Lim, S. S., Prescott, E.C., and Sunder, S., (1994). Stationary Solution to the Overlapping Generations Model of Fiat Money: Experimental Evidence. *Empirical Economics*, **19**: 255- 277.

Lucas, R.E. Jr., (1972). Expectations and the Neutrality of Money, *Journal of Economic Theory*, **4:2**: 103–124.

Lucas, R.E. Jr., (1980). Two Illustrations of the Quantity Theory of Money, *American Economic Review*, **70:5**: (December), 1005-1014.

Marcet, A., and Sargent, T.J., (1989). Convergence of Least Squares Learning Mechanisms in Self Referential, Linear Stochastic Models, *Journal of Economic Theory* **48**: 337–368.

Marimon, R., Spear, S. and Sunder, S., (1993). Expectationally–Driven Market Volatility: An Experimental Study, *Journal of Economic Theory.*

Marimon, R. and Sunder, S., (1993). Indeterminacy of Equilibria in a Hyperinflationary World: Some Experimental Evidence, *Econometrica* **61**: 1073-1107.

Marimon, R.S. and Sunder, S., (1994). Expectations and Learning under Alternative Monetary Regimes: An Experimental Approach, *Economic Theory* **4**: 131-162.

Sargent T.J., (1991). Equilibrium with Signal Extraction from Endogenous Variables, *Journal of Economic Dynamics and Control*, **15**: 245-273.

Sargent, T.J., (1993). *Bounded Rationality in Macroeconomics.* Oxford: Claredon-Oxford University Press.

Sargent, T.J., and Wallace, N., (1982). The Real-Bills Doctrine versus the Quantity Theory: A Reconsideration, *Journal of Political Economy*, **90**: 1212–1235.

Sargent, T.J., and Wallace, N., (1987). Inflation and the Government Budget Constraint in *Economic Policy in Theory and Practice*, (eds.) Assaf Razin and Efraim Sadka. New York: Macmillan.

Woodford, M., (1986). Indeterminacy of Equilibrium in the Overlapping Generations Model: A Survey. Mimeo, Columbia University.

Woodford, M., (1990). Learning to Believe in Sunspots, *Econometrica* **58, 2**: 277-308.