Available online at www.sciencedirect.com
SCIENCE DIRECT
ELSEVIER
Journal of Monetary Economics 50 (2003) 1701–1718
Journal of MONETARY ECONOMICS
www.elsevier.com/locate/econbase

Inside–outside money competition

Ramon Marimon[a,b,c,d,e], Juan Pablo Nicolini[f], Pedro Teles[d,g,h,i,*]

[a] *Universitat Pompeu Fabra, Ramon Trias Fargas 25-27, Barcelona 08005, Spain*
[b] *Centre de Recerca en Economia International, Barcelona, Spain*
[c] *Centre de Referencia en Economia Analitica, Barcelona, Spain*
[d] *Centre for Economic Policy Research, London, UK*
[e] *National Bureau of Economic Research, Cambridge, MA 02138, USA*
[f] *Universidad Torcuato Di Tella, Minones 2177, Buenos Aires, Argentina*
[g] *Federal Reserve Bank of Chicago, 230 S. LaSalle Street, Chicago, IL 60604, USA*
[h] *Banco de Portugal, Lisbon, Portugal*
[i] *Universidade Catolica Portuguesa, Lisbon, Portugal*

Abstract

We study how competition from privately supplied currency substitutes affects monetary equilibria. Whenever currency is inefficiently provided, inside money competition plays a disciplinary role by providing an upper bound on equilibrium inflation rates. Furthermore, if "inside monies" can be produced at a sufficiently low cost, outside money is driven out of circulation. Whenever a 'benevolent' government can commit to its fiscal policy, sequential monetary policy is efficient and inside money competition plays no role.

JEL classification: E40; E50; E58; E60

Keywords: Electronic money; Inside money; Currency competition; Reputation; Inflation

1. Introduction

Payment systems have gone through a major transformation in the last two decades. In particular, electronic payments have risen in most developed countries and are expected to rise even more in the future.[1] The development of the technology

*Corresponding author. Federal Reserve Bank of Chicago, 230 S. LaSalle Street, Chicago, IL 60604, USA. Tel.: +1-312-322-2947; fax: +1-312-322-2357.
E-mail address: pteles@frbchi.org (P. Teles).

[1] For example, Humphrey et al. (1996) find that "in all (14) developed countries but the United States, electronic payments have been either the sole or the primary reason for the 34 percent rise in total noncash payments between 1987 and 1993" (p. 935).

0304-3932/$ - see front matter
doi:10.1016/j.jmoneco.2003.08.009

to transfer information electronically has increased substitutability between deposits and currency in transactions and has substantially reduced the cost of transactions using deposits.[2] Deposits used for electronic payments[3] are highly substitutable for currency because the settling value is ultimately a liability of the financial institution that issues the electronic card (checks, in contrast, are a liability of the purchaser). Clearing electronic transactions is also considerably less expensive than clearing checks (1/3–1/2 of the cost of checks, according to Humphrey et al., 1996). Furthermore, in contrast to currency, deposits used for electronic transactions can pay nominal interest on the average balance at a very low cost.

In spite of the technological developments leading to a widespread use of different forms of electronic money, there has been little theoretical attention on a range of issues raised by this. How is monetary policy affected by the increased competition from inside money? Does the increased efficiency in the supply of inside money induce lower inflation rates? Can the increasing efficiency in the supply of inside money result in a *cashless* economy? In other words, will inside money drive outside money out? In this paper, we investigate the theoretical issues associated with competition between currency and currency substitutes, between outside and inside money.

At first glance, competition between suppliers of currency substitutes and between them and the monopolist supplier of currency should induce a lower price for the use of money and, therefore, lower inflation rates as well as nominal interest rates. However, one reason for high inflation rates, emphasized in the literature, is the time inconsistency of monetary policy; and it is unclear whether exposing monetary authorities to competition will discipline them or possibly worsen the time consistency problem. In other words, the role of competition cannot be analyzed independently of the commitment problem. The aim of this paper is to study these issues in the context of a dynamic monetary general equilibrium model where currency is the unique outside money and where competitively supplied inside monies are perfect substitutes for currency. To this end, we consider monetary regimes that differ in two dimensions regarding the monetary authority: the objective function (whether the aim is to maximize transfers or welfare) and the ability to commit to a policy (whether there is full commitment or policies are sequentially redesigned).

We start the analysis in Section 2 by describing the competitive equilibria for given monetary policies. In Section 3, we show that a government that maximizes transfers (or revenues) and is able to commit to its policies will be induced by competition from currency substitutes to set a low stationary inflation rate. This inflation rate is driven down with the reduction of financial intermediation costs, and approaches a negative number, corresponding to the Friedman rule, as the intermediation costs

[2] According to Humphrey et al. (2003), there has been a major reduction in the operating costs of providing bank payments and other services, associated with the development of electronic payments. They estimate those costs to have fallen by 24% relative to banks' total assets in 12 European countries over 1987–1999.

[3] We call these deposits used for electronic payments, electronic money, which are privately issued currency substitutes, a form of inside money.

approach zero. Since these low inflation equilibrium outcomes are time inconsistent we analyze, in Section 4, the set of sustainable equilibria. In particular, we inquire whether the commitment solution can be sustained through reputation, and how competition from currency substitutes affects the set of sustainable equilibria. We show that the set of sustainable equilibria with valued currency is characterized by inflation rates which are nonnegative and are bounded above. The zero lower bound results from the need of future positive rents for the reputation mechanism to work. The upper bound results from inside money competition since it limits the expected revenues that can be obtained from outside money. When the production of inside money is sufficiently efficient, the corresponding upper bound would become negative and, as a result, there is no equilibrium with valued currency.

Competition between outside and inside money is an interplay between two sources of inefficiency, one resulting from lack of commitment affecting the supply of outside money and the other an assumed technological inferiority in the supply of inside money. Outside money is produced at zero cost but, without commitment, requires inflationary rents to exist in equilibrium. Inside money is produced competitively but at a positive cost. In equilibrium, whether inside or outside money circulates is determined by which of the two sources of inefficiency is dominant. In summary, inside money competition enhances efficiency by constraining the inflation rates that can be sustained in equilibria with valued currency. However, as the intermediation costs are reduced, outside money may be driven out of circulation. In this case, because the economy would be using a more costly technology to supply money, there would be a welfare loss.

In Section 5 we analyze the case of a "representative" government. With full commitment, the Ramsey planner chooses to implement the Friedman rule. Therefore, with commitment, there is no disciplinary role for competition from currency substitutes. Even if the monetary authority cannot commit to future decisions, as long as the fiscal authority is committed to an expenditure and tax policy, it is a time-consistent monetary policy to follow the Friedman rule. This is due to the fact that, once there is commitment to fiscal policy, the zero bound on interest rates leaves no room for enhancing welfare by changing the time pattern of government revenues. It follows that in this regime, inside money competition plays no role independently of whether there is commitment to monetary policy. Only the 'technologically efficient' outside money circulates.

In our model, we abstract from some aspects that distinguish different "currency substitutes". Deposits can be used for transactions through electronic payments in many different ways. Our model allows for the use of deposits for transactions through an arrangement that most resembles debit cards, which allow buyers to make purchases directly using funds from some form of deposit account. Reloadable cash cards would also fit our description of currency substitutes, but these cards are not widely used and do not typically pay interest, although they could.

In our set up, currency substitutes are assumed to be fully backed, default free deposits that are perfect substitutes for currency. The suppliers of these deposits are price takers. Relaxing these assumptions can significantly alter the results. If the suppliers of currency substitutes could default on nominal contracts, then they would, unless the resulting loss of future profits prevented them from doing so. If the suppliers of inside monies were not price takers, then they would have an incentive to overissue in order to devalue outstanding balances. In Marimon et al. (2000), we analyze a monetary arrangement of that type as an example of how the reputation and the competition mechanisms interact.

That alternative environment is also analyzed in Klein (1974), with "…one dominant money (currency supplied by a government monopoly) and many privately produced nondominant monies (deposits supplied by different commercial banks)." Klein asked most of the questions that we address in this paper. In particular, he made it clear that competition between the private issuers of currency substitutes and between them and the monopolist issuer of currency did not dismiss and could even raise intertemporal consistency problems. However, he did not provide a full characterization of the equilibrium set as we do in this paper. To our knowledge, Taub (1985) has been the only previous attempt to study "currency competition" taking into account reputational aspects using a dynamic general equilibrium framework.[4]

2. Competitive monetary equilibria

In this section, we describe the economic environment and characterize its monetary equilibria for a given policy. The economy is populated by a large number of identical infinitely lived households, financial intermediaries, and a government. The households have preferences defined over consumption of a *cash* good, c_t^1, consumption of a credit good, c_t^2, and total labor, n_t, for any period $t \geqslant 0$,

$$V = \sum_{t=0}^{\infty} \beta^t [u(c_t^1) + u(c_t^2) - \alpha n_t]. \tag{2.1}$$

Assuming that leisure enters linearly into the utility function is in no way essential, but significantly simplifies the analysis. The function u is increasing, strictly concave, and differentiable.

The households are endowed with a unit of time that can be used for leisure or total labor, n_t, which can be allocated to the production of the consumption goods or the production of deposits, n_t^e. The production technology of the consumption goods is linear with unitary coefficients. Thus, feasibility requires that

$$c_t^1 + c_t^2 = n_t - n_t^e.$$

We use the timing of transactions as found in Svensson (1985). The goods market meets in the beginning of the period. The cash good, c_t^1, must be purchased using either currency, M_t, or privately issued currency substitutes, E_t, which have been carried over from the previous period. Currency substitutes are deposits that the buyers can easily access, for example using electronic cards. The credit good, wages,

[4] In contrast with this paper, Taub (1985) only considers time-consistent stationary policies and, therefore, cannot provide a full characterization of equilibria with reputation and competition.

and government transfers are paid at the end of the period in the assets market where the households can adjust their portfolios of currency, deposits, and real bonds. In principle, currency and currency substitutes do not have to be traded at par. In other words, there are two nominal units of account corresponding to the two payment systems. Goods are priced in units of these two assets; that is, P_t^m is the price of goods in currency and P_t^e is the corresponding price in privately issued currency substitutes. The corresponding exchange rate in period t is $\varepsilon_t = P_t^m / P_t^e$, which denotes the price of deposits in units of currency. We focus our attention on three types of equilibria. In the first type of equilibria, both currency and deposits are valued, meaning that if the supply was positive and finite, the price would be finite. Because of perfect substitutability the exchange rate is indeterminate. We look at equilibria where the two monies trade at par, $\varepsilon_t = 1$, and where the supply and demand of deposits is zero, $E_t = 0,\ t \geqslant 0$. In the second type of equilibria, currency is never valued. Only deposits are used for transactions. If $M_t > 0$, then $\varepsilon_t = \infty$. Finally, we also consider a third type of equilibria where deposits have zero value, but currency is valued. In this case, if $E_t > 0$, then $\varepsilon_t = 0$. There are no equilibria where both monies have zero value. We use P_t to denote the price of goods in the relevant unit of account. Thus, when currency is valued, including the case in which deposits are also valued, $\varepsilon_t = 1,\ t \geqslant 0$, then $P_t = P_t^m$, and when only inside money circulates, then $P_t = P_t^e$.[5]

The representative household is endowed with initial holdings of money M_0 and of real bonds valued at $R_0 b_0^h$, as well as initial deposits that are assumed to be zero, $I_0^f E_0 = 0$. We assume for convenience that $R_0 = \beta^{-1}$. The household chooses sequences of consumptions and labor $\{c_t^1, c_t^2, n_t\}$ and portfolios $\{M_{t+1}, b_{t+1}^h, E_{t+1}\}$, $t \geqslant 0$, treating parametrically prices and interest rates $\{P_t, \varepsilon_t, R_{t+1}, I_{t+1}^f\}_{t=0}^{\infty}$, government transfers $\{g_t\}_{t=0}^{\infty}$, and dividends from financial intermediaries $\{\Pi_t\}_{t=0}^{\infty}$. I_{t+1}^f is the gross interest on deposits held from period t to $t+1$ in units of deposits. If both outside and inside money are valued forever, i.e., $\varepsilon_t = 1,\ t \geqslant 0$, the household intertemporal budget and cash-in-advance constraints for $t \geqslant 0$ are

$$\begin{aligned} & M_{t+1} + P_t b_{t+1}^h + E_{t+1} \\ & \quad \leqslant M_t + P_t R_t b_t^h + I_t^f E_t - P_t(c_t^1 + c_t^2) + P_t n_t + P_t g_t + \Pi_t, \end{aligned} \tag{2.2}$$

$$P_t c_t^1 \leqslant M_t + E_t \tag{2.3}$$

and a no-Ponzi scheme condition that guarantees that the present value budget is satisfied.[6] Notice that there is no nominal interest paid on currency, while deposits

[5] In our environment with a dominant money (currency) and privately issued deposits, it would be natural to assume a *one-sided convertibility legal requirement* in that deposits are convertible on demand into currency at a one-to-one fixed exchange rate. This convertibility requirement implies that, in equilibrium, $\varepsilon_t \geqslant 1$. If $\varepsilon_t < 1$, depositors would exercise their option to convert their deposits at par value.

[6] If inside money is not valued, i.e., $\varepsilon_t = 0,\ t \geqslant 0,\ E_t$ must be replaced by $\varepsilon_t E_t$ in the constraints and, similarly, if currency is not valued, i.e., $\varepsilon_t = \infty,\ t \geqslant 0,\ M_t$ must be replaced by M_t/ε_t.

E_{t+1} are remunerated by financial intermediaries at the gross nominal interest rate, I^f_{t+1}. The nominal interest rate on bonds is given by $I_{t+1} \equiv (P_{t+1}/P_t)R_{t+1}$.

Since currency does not pay nominal interest, in the equilibria where both currency and deposits are valued, and $\varepsilon_t = 1,\ t \geqslant 0$, it must be that $I^f_{t+1} = 1,\ t \geqslant 0$. Then an equilibrium allocation must satisfy, for $t \geqslant 0$,

$$\frac{u'(c^1_{t+1})}{\alpha} = I_{t+1}, \tag{2.4}$$

$$\frac{u'(c^2_t)}{\alpha} = 1, \tag{2.5}$$

$$R_{t+1} = \beta^{-1}. \tag{2.6}$$

In an equilibrium where currency is never valued and where only deposits are used for transactions, Eq. (2.4) is replaced with

$$\frac{u'(c^1_{t+1})}{\alpha} = 1 + I_{t+1} - I^f_{t+1} \tag{2.7}$$

meaning that the cost of holding inside money is the difference between the return on bonds and the return on deposits. To simplify notation, from now on we use the fact that in equilibrium the real rate of return on bonds always satisfies (2.6).

Private issuers of inside money: The financial intermediation sector is competitive. A representative issuer of *inside money* offers deposits E_{t+1} at a gross interest rate I^f_{t+1}. We assume that these contracts are enforceable, possibly through banking regulation. The financial intermediation technology is such that they must pay a real cost, in units of labor, for the supply of deposits, at redemption time, as a fraction of the real value of the outstanding deposits: $n^e_t = \theta E_t/P_t$. The financial intermediary holds the total amount deposited, E_{t+1}, as bonds, $P_t b^e_{t+1}$, which pay gross interest I_{t+1}. The cash flow of the financial intermediary in period $t \geqslant 0$ is

$$\Pi_t = E_{t+1} - E_t I^f_t - P_t b^e_{t+1} + P_t b^e_t \beta^{-1} - P_t n^e_t.$$

Free entry in the financial intermediation sector results in $\Pi_{t+1} = 0,\ t \geqslant 0$, which, given that $E_{t+1} = P_t b^e_{t+1}$ and $P_t n^e_t = E_t \theta$, implies

$$I_{t+1} - I^f_{t+1} = \theta, \quad t \geqslant 0. \tag{2.8}$$

Recall that we assume that financial intermediaries are price takers and honor their liabilities. If they were not price takers, then it would be optimal to surprise the households and overissue. This overissuing would have an impact on the price level and would reduce the real value of the nominal liabilities of the financial intermediary. Similarly, if the deposit contracts could not be enforced then they would have an incentive, in any given period, to default on deposits.[7]

Government: Given $(M_0, R_0 d_0)$, a government policy consists of a sequence of transfers $\{g_t\}_{t=0}^{\infty}$, that can be negative, and a monetary and debt policy

[7] Marimon et al. (2000) study the case of private issuers of currency who are neither price takers nor necessarily credible.

$\{M_{t+1}, d_{t+1}\}_{t=0}^{\infty}$. For now, we abstract from sources of revenues other than seigniorage; therefore, in the equilibria where both currency and deposits are valued, the intertemporal budget constraint of the government is

$$M_{t+1} + P_t d_{t+1} \geqslant M_t + P_t R_t d_t + P_t g_t \tag{2.9}$$

together with a no-Ponzi games condition.

In setting its policy, the government takes into account the competitive behavior of the private sector. Using (2.6), the present value budget constraint can be written as

$$\sum_{t=0}^{\infty} \beta^t g_t \leqslant \sum_{t=0}^{\infty} \beta^{t+1}(I_{t+1} - 1)m(I_{t+1}) - \frac{M_0}{P_0} - R_0 d_0, \tag{2.10}$$

where $I_{t+1} = \beta^{-1} P_{t+1}/P_t$ and $m(I)$ is defined implicitly by (2.4) together with the cash-in-advance constraint, i.e., $m(I) = u'^{-1}(\alpha I)$. In the equilibria where currency is not valued the budget constraint would be

$$\sum_{t=0}^{\infty} \beta^t g_t \leqslant -R_0 d_0. \tag{2.11}$$

It is well known, that, in general, for a given money supply policy $\{M_{t+1}\}_{t=0}^{\infty}$ there are multiple competitive equilibria, with different paths for the initial price level and interest rates $(P_0, \{I_{t+1}\}_{t=0}^{\infty})$. We will focus our attention on equilibria with constant rates of money growth, from period $t = 1$ on. In this case, in addition to stationary equilibria there may be multiple nonstationary equilibria. We only consider the equilibria that are stationary from period $t = 1$ on.

Competitive equilibria: Given $(M_0, R_0 d_0, R_0 b_0^h, R_0 b_0^e, I_0^f E_0)$ and a prespecified government policy $\{M_{t+1}, d_{t+1}, g_t\}_{t=0}^{\infty}$, a *competitive equilibrium* where inside and outside money are valued (i.e. $\varepsilon_t = 1,\ t \geqslant 0$)[8] consists of sequences of price levels and interest rates $\{P_t, R_{t+1}, I_{t+1}^f\}_{t=0}^{\infty}$, households' allocations $\{c_t^1, c_t^2, n_t, M_{t+1}, E_{t+1}, b_{t+1}^h\}_{t=0}^{\infty}$, and financial intermediaries' allocations $\{n_t^e, E_{t+1}, b_{t+1}^e\}_{t=0}^{\infty}$, such that households maximize their utility subject to their budget constraints, financial intermediaries maximize profits, and markets clear; that is, for $t \geqslant 0$, $c_t^1 + c_t^2 = n_t - n_t^e$; $n_t^e = \theta E_t / P_t$; $d_t = b_t^h + b_t^e$.

Equilibria with valued currency: As previously mentioned, we are interested in the characterization of stationary equilibria (from period one on) where one or both forms of monies are valued. In equilibria where currency is held, the cost of holding currency must be less than or equal to the cost of holding deposits;

$$I_{t+1}^f \leqslant 1$$

must hold. Since the cost of holding deposits is $I_{t+1} - I_{t+1}^f = \theta$, in a stationary equilibrium with valued currency it must be that either $I_{t+1} = I < 1 + \theta,\ t \geqslant 0$ or $I_{t+1} = 1 + \theta,\ t \geqslant 0$. In equilibria with $I < 1 + \theta,\ t \geqslant 0$, deposits do not have value. This means that if the supply of deposits is positive, $E_t > 0$, the exchange rate must be

[8] The competitive equilibria where either only outside money or only inside money is valued are defined analogously.

$\varepsilon_t = 0$. When $I_{t+1} = 1 + \theta,\ t \geqslant 0$, the households are indifferent between holding currency and deposits. We will assume that only currency is held, so that $E_t = 0$.

Cashless equilibria: In an equilibrium where currency is not valued and only deposits are used for transactions, the price level is $P_t = P_t^e$, and both the nominal interest rate on deposits, I_t^f, and on bonds, I_t, are in units of deposits. There is a unique such equilibrium, up to the determination of all nominal variables. Furthermore, there is no equilibrium where neither currency nor deposits are valued.[9] In the equilibrium with valued deposits, if the supply of currency is positive, $M_t > 0$, then $\varepsilon_t = \infty$. The incremental cost of the cash good is equal to the difference between the interest rate on bonds and the one on deposits, that is, the intermediation cost, θ (i.e., $I_{t+1} - I_{t+1}^f = \theta,\ t \geqslant 0$).

In this economy with inside money, the nominal supply of deposits is indeterminate. It follows that price levels are also indeterminate. The interest rates are also indeterminate, but the difference between the two interest rates is not, and that is what is relevant to determining the allocations. All of the real quantities except the initial consumption of the cash good are determined by $u'(c_t^2) = \alpha; u'(c_{t+1}^1) = \alpha(1+\theta)$ and $n_t = c_t^2 + c_t^1(1+\theta),\ t \geqslant 0$. Since $c_0^1 = E_0/P_0 I_0^f$, the initial consumption of the cash good is indeterminate if $E_0 I_0^f > 0$. Assuming $E_0 I_0^f = 0$ avoids this indeterminacy without affecting the characterization of equilibria from period one on.[10]

3. Equilibria with commitment

In this section, we consider full commitment policies under the assumption that the government chooses the policy $(\{M_{t+1}\}, \{d_{t+1}\}, \{g_t\})$ that maximizes its preferences for revenues (or transfers). More precisely, we assume that the government's problem is to maximize $\sum_{t=0}^{\infty} \beta^t G(g_t)$ (where, for standard reasons, the function G is assumed to be increasing and strictly concave), subject to (2.10). Thus, given that in equilibrium the gross real interest rate is constant and equal to β^{-1}, the government will always choose a constant sequence of transfers. Therefore, the value to the government of different allocations can be measured in terms of g.

In the full commitment optimal program the value of the outstanding initial money balances is zero, $M_0/P_0 = 0$. The choices of interest rates are likely to be constrained by the presence of currency substitutes. To see this, notice that without inside money competition, revenues from the inflation tax are given by $f(I) = (I-1)m(I)$. We assume that the function $f(I)$ has a unique maximum I^*, and that $f'(I) > 0$ for $I^* > I \geqslant 1$ and $f'(I) < 0$ for $I > I^*$. If, for example, u is of the CRRA form then f satisfies these assumptions. Whenever $f'(1+\theta) \geqslant 0$, i.e., revenues from

[9] The formal treatment of the existence and nonuniqueness of monetary equilibria in economies with inside money only is, to our knowledge, best performed by Drèze and Polemarchakis (2000).

[10] This cashless economy is not the limit of economies with well defined currency demands, as in Woodford (1998) and, therefore, it is not possible to determine the initial price level in our cashless equilibrium as the limit of a sequence of equilibria with valued currency.

the inflation tax are nondecreasing at $1+\theta$, the unconstrained choice of the interest rate is greater than or equal to $1+\theta$. Inside money competition prompts the government to choose $I = 1+\theta$. Condition (2.8) implies that $I^f_{t+1} = 1$. More formally,

Proposition 1. *Assume there exists $I^* > 1+\theta$ such that $f'(I) > 0$ for $I^* > I \geqslant 1$ and $f'(I) < 0$ for $I > I^*$. Then, the commitment solution for the revenue maximizing government is $I_{t+1} = 1+\theta$, resulting in $I^f_{t+1} = 1$ for $t \geqslant 0$.*

It follows as a corollary that as the intermediation costs are reduced (i.e., $\theta \searrow 0$)—for example, because the suppliers of currency substitutes become more efficient—the commitment equilibrium approaches the Friedman rule, where the rents to the monopolist supplier of currency are zero.

The commitment solution is time inconsistent. In this solution, at time zero, the government runs a *big open market operation* holding real bonds issued by the private sector that are exchanged for currency so that the real value of the outstanding money stock is zero. In addition, monetary policy from time one on is such that the gross nominal interest rate is constant over time and set at $1+\theta$. At time $t \geqslant 1$, the government has outstanding liabilities $[M_t/P_t + \beta^{-1} d_t]$, so that if it was able to commit from time t on, it would be optimal to revise the plan by setting $M_t/P_t = 0$, thereby conducting another *big open market operation*. The interest rate plan $I_t = 1+\theta$ will not necessarily be optimal for a government that can decide sequentially. Therefore, we turn our attention to an economy without a fully committed monetary authority.

4. Equilibria without commitment

In this section, we define and characterize equilibria when the government makes choices sequentially. These decisions depend on the history of the economy, which is given by

$$h_0 = \{M_0, R_0 d_0, R_0 b^h_0, R_0 b^e_0, I^f_0 E_0\} \text{ and } h^1_{t+1} = \{h_t, M_{t+1}, d_{t+1}, g_t\}, \text{ for } t \geqslant 0$$
$$\text{and } h_{t+1} = \{h^1_{t+1}, b^h_{t+1}, b^e_{t+1}, E_{t+1}\}, \text{ for } t \geqslant 0.$$

Given a history h_t at the beginning of period t, the government moves first and chooses the policy for the period (g_t, M_{t+1}, d_{t+1}).[11] Thus, h^1_{t+1} is known within period t, at the time households and financial intermediaries make their choices.

A *sequential policy* for the government is a sequence of functions $\sigma = \{\sigma_t\}^\infty_{t=0}$, where $\sigma_t(h_t)$ specifies the choice of a government *action* (g_t, M_{t+1}, d_{t+1}) as a function of the history h_t. As in the commitment case, the government takes the competitive behavior of the private sector as a given when choosing a policy. An allocation rule for the private sector η is a sequence of functions $\{\eta_t\}^\infty_{t=0}$, where $\eta_t(h^1_{t+1})$ specifies a

[11] The implementation of the policy has to obey the timing of transactions spelled out in Section 2 where good markets open first and asset markets open at the end of the period, taken from Svensson (1985).

one-period allocation for households and financial intermediaries $(c_{1t}, c_{2t}, n_t, M^d_{t+1}, E_{t+1}, b^h_{t+1}, b^e_{t+1})$ as a function of the history h^1_{t+1}. If $\sigma^t(h_t)$ denotes the continuation of σ from h_t, *sequential rationality* implies that for each $(t,\ h_t), \sigma^t(h_t)$ is optimal (i.e., maximizes transfer revenues subject to (2.10)) given the allocation rules of the households.

A *Sustainable Equilibrium* (SE) is a pair (σ, η) such that: (i) (σ, η) defines a *competitive equilibrium*, with corresponding prices $\{P_t, \varepsilon_t, R_{t+1}, I^f_{t+1}\}^{\infty}_{t=0}$ and (ii) for each (t, h_t), $\sigma^t(h_t)$ is optimal given η.

In order to characterize the set of sustainable equilibrium values, we first need to identify the worst one.

Proposition 2. *The value of a competitive equilibrium where currency is not held and deposits are used for transactions is the value of the worst sustainable equilibrium.*

Proof. Let η be the allocation rule for the private sector corresponding to an equilibrium where only inside money is valued (as defined in Section 2). Let the strategy of the government σ be given by $M_{t+1} = (1 + \hat{\mu})M_t$, where $(1 + \hat{\mu})\beta^{-1} > 1 + \theta,\ d_t = d_0,\ g_t = -(\beta^{-1} - 1)d_0$, for all t. Currency is dominated and is not held in the equilibrium defined by (σ, η). Since currency is not valued, such a policy is sequentially rational for the government. It follows that the value of this equilibrium outcome, measured by the constant flow of government transfers, is

$$V^{\mathrm{WSE}}(d_0) = -(\beta^{-1} - 1)d_0, \tag{4.1}$$

where WSE stands for worst sustainable equilibrium. In fact, the government can always guarantee this payoff, so that there is no sustainable equilibrium with a value lower than $V^{\mathrm{WSE}}(d_0)$. $\square$

In line with Chari and Kehoe (1990), we apply Abreu (1988)'s optimal penal codes and use the reversion to the worst sustainable equilibrium as the means of supporting equilibrium outcomes. As mentioned above, we will concentrate on stationary equilibria, except for the initial big open market operation.

More explicitly, consider the following government strategy $\sigma : M_1 = BM_0,\ M_{t+1} = (1 + \mu')M_t,\ t \geqslant 1,\ g_t = g = \mu' m(I') - d_1(\beta^{-1} - 1)$, and $d_{t+1} = d_1 = d_0 - \beta m(I')$, for all $t \geqslant 0$, as long as $M_s = (1 + \mu')M_{s-1}$, for $2 \leqslant s \leqslant t$, and $M_1 = BM_0$, where $I' = (1 + \mu')\beta^{-1} \leqslant 1 + \theta$. If $M_1 \neq BM_0$, then for $t \geqslant 1$, $M_{t+1} = (1 + \hat{\mu})M_t,\ g_t = -d_1(\beta^{-1} - 1)$, and $d_{t+1} = d_1$, where $(1 + \hat{\mu})\beta^{-1} > 1 + \theta$; and if $M_s \neq (1 + \mu')M_{s-1}$ for at least one $s \geqslant 2$, then, for $t \geqslant s$, $M_{t+1} = (1 + \hat{\mu})M_t,\ g_t = g_s = -d_s(\beta^{-1} - 1)$, and $d_{t+1} = d_s$, where $(1 + \hat{\mu})\beta^{-1} > 1 + \theta$. We consider the limiting equilibria as $B \to \infty$. For $I' = 1 + \theta$, the limiting strategy corresponds to following the policy achieved under full commitment (Proposition 1), as long as such a full commitment path has been followed previously, while a deviation to an inside money equilibrium—without cash, as in Proposition 2—follows if a deviation from the full commitment path is observed.

As we have seen (Proof of Proposition 1), the value for the government after a deviation is $V^{\mathrm{WSE}}(d_t)$. Therefore, it is not profitable for the government to deviate from the path of constant growth of the money supply μ' if $V(I'; d_t) \geqslant V^{\mathrm{WSE}}(d_t),\ \ t \geqslant 1$, where

$$\begin{aligned} V(I'; d_t) &= \beta(I' - 1)m(I') - (1 - \beta)(m(I') + d_t\beta^{-1}),\ \ t \geqslant 1 \\ &= (\beta I' - 1)m(I') + V^{\mathrm{WSE}}(d_t),\ \ t \geqslant 1. \end{aligned}$$

At $t = 0$, the value of the equilibrium with I', $V(I'; d_0) = \beta(I' - 1)m(I') - (1 - \beta)d_0\beta^{-1}$ is always higher than $V^{\mathrm{WSE}}(d_0)$. $V(I'; d_t) \geqslant V^{\mathrm{WSE}}(d_t)$, for all t, only if $\beta I' - 1 = \pi' \geqslant 0$, where π' is the, constant, inflation rate when I' is the gross nominal interest rate.

So far, we have shown that sustainability requires the inflation rate to be nonnegative.[12] In addition, competition from currency substitutes requires $I' = (1 + \pi')\beta^{-1} \leqslant 1 + \theta$. Thus, the set of (from period one) stationary sustainable competitive outcomes with valued currency is characterized by inflation rates satisfying

$$0 \leqslant \pi \leqslant \beta(1 + \theta) - 1. \tag{4.2}$$

In the absence of competition from currency substitutes, the set of sustainable equilibria is a very large one that includes the commitment solution, i.e. the stationary inflation rate that allows achieving the maximum of the Laffer curve. As long as that value is positive, the equilibrium is sustainable. The punishment is autarchy, but from the perspective of a revenue maximizing government, autarchy has the same value as the deposits-only equilibrium.

Competition reduces the set of sustainable inflation rates by imposing an upper bound on equilibrium inflation when currency is valued. Thus, competition from currency substitutes allows to reduce the maximum level of the inflation rate in a sustainable equilibrium.

Because competition from currency substitutes reduces the future gains from issuing currency, it is more difficult to sustain equilibria where currency has value. If the supply of currency substitutes is very efficient, the set of sustainable equilibria with valued currency may be empty. That would be the case if, under commitment, competition from currency substitutes drove the inflation rates into negative numbers, which would happen if $\theta < \beta^{-1} - 1$. In that case, there would be no sustainable equilibrium with valued currency but there would still be a sustainable equilibrium outcome with deposits being used for transactions. In this equilibrium, the cost of transactions is given by the real intermediation cost θ. It follows that, with limited commitment, relatively less efficient competitors can drive currency out of circulation.

Proposition 3. *The policy with full commitment* (*of Proposition* 1), *characterized by* $I_{t+1} = 1 + \theta$, *is sustainable if the intermediation cost* θ *satisfies* $\theta \geqslant \beta^{-1} - 1$; *i.e., if the equilibrium inflation rate is nonnegative*, $\pi \geqslant 0$. *If* $\theta < \beta^{-1} - 1$, *there is no sustainable equilibrium with valued currency*, *but there is a sustainable equilibrium with* (*only*) *inside money.*

[12] If there was nominal debt, the corresponding lower bound on inflation rates would be strictly positive.

When the policy with full commitment is sustainable, the set of sustainable equilibria can be relatively large although, as (4.2) shows, it shrinks with the costs of supplying inside money. Efficiency is thus enhanced as these costs are reduced, to the point where outside money is driven out of circulation. At this point there would be a discrete loss of welfare, because of the use of a relatively more costly technology to supply money. In turn, this cost would be minimized as the inside-money technology becomes increasingly efficient.

5. The case of a representative government

In this section, we show how the results we have obtained so far are modified when we assume that the government maximizes welfare. As in the standard Ramsey problem, we assume exogenous—per period—government expenditures, g. As the ability to collect seigniorage will be limited by the efficiency of the financial intermediaries, we allow for the government to levy consumption taxes, τ_t, as well as taxes on the production of inside money, τ_t^e, to ensure that expenditures can be financed. In this paper, we concentrate on the choice of monetary policy and therefore we maintain full commitment on the choice of tax policy, in addition to exogeneity of expenditures. We allow for monetary policy to be chosen with and without commitment.

As in the previous section, the timing of events is as in Svensson (1985). Nicolini (1998) shows that with this timing, the time inconsistency problem of a Ramsey government is of a different nature than in the classic papers of Calvo (1978) and Lucas and Stokey (1983), since there are costs of unanticipated inflation. The two main differences that this timing introduces are that the optimal deviation for inflation is always finite and that for the government to be willing to deviate from the Ramsey policy and inflate at a higher rate, the price elasticity of consumption has to be larger than one. We will assume that this is indeed the case. Nicolini (1998) obtains these results in an environment where seigniorage is the sole source of revenue. In our set up there are alternative taxes which implies that the optimal monetary policy is characterized by the Friedman rule. As we show in this section, in our economy, when there is commitment to tax policy, the monetary policy is time consistent.

The consumer's problem is the same as before, except for the presence of a tax on consumption. We simplify the analysis in this section by assuming preferences of form (2.1), but with the additional restriction of constant relative risk aversion (CRRA), i.e., $-u''(c_t)c_t/u'(c_t) = \rho > 0$), where $1/\rho$ is the price elasticity of c_t. For the reasons stated above, we assume that $\rho < 1$. If $\varepsilon_t = \varepsilon \in \{0, 1\}$, $t \geqslant 0$, the budget and cash-in-advance constraints are

$$M_{t+1} + P_t b_{t+1}^h + \varepsilon_t E_{t+1} \leqslant P_t n_t - (1 + \tau_t) P_t (c_t^1 + c_t^2) + M_t + P_t R_t b_t^h + I_t^f \varepsilon_t E_t \tag{5.1}$$

$$(1 + \tau_t) P_t c_t^1 \leqslant M_t + \varepsilon_t E_t \tag{5.2}$$

for $t \geqslant 0, M_0, R_0 b_0^h, E_0 = 0$ given. Again, we assume that $R_0 = \beta^{-1}$.

The tax on consumption imposes a distortion between consumption and leisure, shown in the following first-order conditions for $t \geqslant 0$:

$$\frac{u'(c_t^2)}{\alpha} = 1 + \tau_t, \quad t \geqslant 0. \tag{5.3}$$

As before, when currency has value, the marginal rate of substitution between the two consumption goods is such that

$$\frac{u'(c_{t+1}^1)}{u'(c_{t+1}^2)} = I_{t+1}, \ \ t \geqslant 0. \tag{5.4}$$

When only inside money circulates the consumptions of the two goods satisfy

$$\frac{u'(c_{t+1}^1)}{u'(c_{t+1}^2)} = 1 + I_{t+1} - I_{t+1}^f, \quad t \geqslant 0. \tag{5.5}$$

Since there are consumption taxes the real value of deposits is $E_t/(1+\tau_t)P_t$. The financial intermediation technology is described by $n_t^e = \theta E_t/(1+\tau_t)P_t$. The financial intermediaries pay a tax on time used to produce money, τ_t^e. Free entry in the financial intermediation sector results in

$$I_{t+1} - I_{t+1}^f = \frac{(1+\tau_{t+1}^e)\theta}{1+\tau_{t+1}}, \quad t \geqslant 0. \tag{5.6}$$

If, as it will be shown to be the case, $\tau_{t+1}^e = \tau_{t+1}$, then (5.5) and (5.6) imply

$$\frac{u'(c_{t+1}^1)}{u'(c_{t+1}^2)} = 1 + \theta, \quad t \geqslant 0. \tag{5.7}$$

5.1. Optimal policy under commitment

The optimal policy under commitment is the solution of a dynamic Ramsey problem, as in Lucas and Stokey (1983); like they did, we follow the primal approach. The objective of the government is to maximize the welfare of the representative household, subject to feasibility and other competitive equilibrium constraints. These other competitive equilibrium constraints are consolidated in an implementability condition.

We first consider the case where $I_{t+1}^f \leqslant 1$ and only currency is used for transactions. The budget constraint of the households, from any period $t \geqslant 0$ on, can be written as follows, provided that the cash-in-advance constraint is satisfied with equality for all $t \geqslant 0$:

$$\sum_{s=1}^{\infty} \beta^s \{(1+\tau_{t+s})[I_{t+s}c_{t+s}^1 + c_{t+s}^2] - n_{t+s}\} + (1+\tau_t)(c_t^1 + c_t^2) - n_t$$
$$\leqslant (1+\tau_t)c_t^1 + b_t^h \beta^{-1}. \tag{5.8}$$

This constraint, for $t = 0$, satisfied with equality, together with (5.3) and (5.4), can be used to build the following implementability condition, which is a necessary condition for the optimal solution to be decentralized as a competitive equilibrium with taxes:

$$\sum_{t=1}^{\infty} \beta^t [u'(c_t^1)c_t^1 + u'(c_t^2)c_t^2 - \alpha n_t] + u'(c_0^2)c_0^2 - \alpha n_0 - \alpha d_0 \beta^{-1} = 0. \tag{5.9}$$

We can now define the Ramsey problem as the maximization of the utility function subject to (5.9) and

$$c_t^1 + c_t^2 + g - n_t \leqslant 0, \quad t \geqslant 0. \tag{5.10}$$

In the following proposition we characterize the Ramsey solution.

Proposition 4. *Let the utility function u be CRRA and* $\rho < 1$. *The Ramsey solution is such that* $I_{t+1} = 1$ *and* $\tau_t^c = \tau^R$, *for* $t \geqslant 0$. *Furthermore,* $c_0^1 \equiv c_0^R < c_t^2 = c_{t+1}^1 = c^R, \ t \geqslant 0$.

Proof. The result follows directly from the first-order conditions of the Ramsey problem. Let $\gamma \geqslant 0$ be the Lagrange multiplier associated with condition (5.9). Then, $u'(c_0^1)/u'(c_0^2) = 1 + \gamma(1-\rho)$, and, for $t \geqslant 0$, $I_{t+1} = u'(c_{t+1}^1)/u'(c_{t+1}^2) = (1+\gamma(1-\rho))/(1+\gamma(1-\rho)) = 1$ and $1 + \tau_t = u'(c_t^2)/\alpha = (1+\gamma)/(1+\gamma(1-\rho))$.

We have set up the Ramsey problem assuming that the cash-in-advance constraints were satisfied with equality. That is indeed the case if $u'(c_t^1)/\beta u'(c_{t+1}^1) \geqslant (1+\tau_t)P_t/((1+\tau_{t+1})P_{t+1}), \ t \geqslant 0$. At the Ramsey optimum $\beta P_t/P_{t+1} = 1/I_{t+1} = 1$, and $\tau_t = \tau^R$. The time zero cash-in-advance constraint is satisfied with equality if $c_0^1 \leqslant c_1^1$, which is the case provided $\rho \leqslant 1$.

We have also assumed that the optimal policy resulted in $I_{t+1}^f \leqslant 1$. Suppose that $I_{t+1}^f > 1, \ t \geqslant 0$. In that case only inside money circulates and the Ramsey problem is the one in the cashless economy.

The budget constraint of the households in the cashless economy after a deviation at some period $t \geqslant 0$ can be written as

$$\sum_{s=1}^{\infty} \beta^s \{(1+\tau_{t+s})[(1+(I_{t+s} - I_{t+s}^f))c_{t+s}^1 + c_{t+s}^2] - n_{t+s}\} \\ + (1+\tau_t)c_t^2 - n_t \leqslant d_t \beta^{-1}. \tag{5.11}$$

with $c_t^1 = 0$, since $E_t = 0$. For $t = 0$, this budget constraint and the first-order conditions (5.5), (5.6), (5.3) can be summarized in the single implementability condition, (5.9), together with $c_0^1 = 0$. The feasibility condition is

$$(1+\theta)c_t^1 + c_t^2 + g - n_t \leqslant 0, \quad t \geqslant 0. \tag{5.12}$$

The Ramsey problem is to maximize the utility function, subject to feasibility, (5.12) and implementability, (5.9), with $c_0^1 = 0$.

The solution is given by a constant consumption tax, $\tau_t = \tau, \ t \geqslant 0$, and by a tax on the production of money that equals the consumption tax, $\tau_{t+1}^e = \tau_{t+1} = \tau, \ t \geqslant 0$. This way both cash and credit goods are taxed at the same rate, τ.

Using (5.7), $u'(c^1_{t+1})/u'(c^2_{t+1}) = 1+\theta$, for $t \geqslant 0$, and $c^1_0 = 0$. However, these marginal rates of substitution and initial consumption of the cash good were a feasible solution to the Ramsey problem, as set up above, by choosing $I_{t+1} = 1+\theta$ (resulting in $I^f_{t+1} = 1$) and a zero initial price of money. That (suboptimal) policy would increase revenues, by $\sum_{t=0}^{\infty} \beta^{t+1}\theta c^1_{t+1}$, and save on intermediation costs, relatively to a policy that implies $I^f_{t+1} > 1$. It follows that the Ramsey solution is such that $I^f_{t+1} \leqslant 1$, $t \geqslant 0$, so that currency substitutes will not be held, and only currency will be used for transactions. □

This proposition states that under commitment, a benevolent government will follow the Friedman rule, $I_{t+1} = 1$, $t \geqslant 0$. The Friedman rule means that both cash and credit goods, from period one on, are taxed at the same rate. This is the optimal taxation solution since the utility function is homothetic in the two goods and separable in leisure—which are the conditions for uniform taxation of Atkinson and Stiglitz (1972), as highlighted by Lucas and Stokey (1983) and Chari et al. (1996). It also follows from standard optimal taxation principles that, since the price elasticity is greater than one ($\rho < 1$), the consumption in period 0 of the cash good is lower than the consumption from period 1 on. That is, there is a higher tax on the initial cash good (with a price elasticity of one).[13]

Under the Friedman rule the price level will be decreasing at the rate of time preference, $P_{t+1} = \beta P_t$, $t \geqslant 0$. The following path for the money supply supports the optimal allocation and prices: $M_{t+1} = \beta M_t$, $t \geqslant 1$, and $M_1 = \beta c^R / c^R_0 M_0$. Notice that the growth rate of money is higher at time zero than from time one on.

5.2. *Optimal monetary policy without commitment*

In this section, we discuss the implications of relaxing the assumption that the government is able to commit to monetary policy. We maintain the assumption of commitment to fiscal policy while monetary policy is sequentially decided and implemented. Such a regime is consistent with an institutional arrangement where there exists a well developed commitment technology for fiscal policy (e.g., fiscal policies are infrequently revised and have to be approved by parliaments), while that may not be the case for monetary policy. As we will see, once the government is committed to an optimal fiscal policy, there are no incentives for the monetary policy to deviate from the optimal Friedman rule. The reason is that government expenditures and alternative tax revenues are determined in period zero, and, furthermore, the monetary authority cannot reduce revenues in future periods. Thus, it has no incentive to increase revenues either. The following proposition states the time consistency of monetary policy.

Proposition 5. *Assume that the government can commit to tax policy. Then, the full commitment optimal monetary policy is time consistent.*

[13] See Nicolini (1998) for a further discussion of this.

Proof. In each period $t \geqslant 1$, the problem of a government that considers revising the Ramsey monetary policy is to maximize

$$\sum_{s=0}^{\infty} \beta^s [u(c^1_{t+s}) + u(c^R) - \alpha(c^1_{t+s} + c^R + g)]$$

subject to the implementability condition

$$\sum_{s=1}^{\infty} \beta^s \left\{ \left[\frac{u'(c^1_{t+s})}{\alpha} - 1\right] c^1_{t+s} + \tau^R c^R - g \right\} + \tau^R c^R - g - c^1_t - d^R_1 \beta^{-1} = 0 \qquad (5.13)$$

and subject to the restriction that the nominal interest rate is nonnegative. Given (5.4), the latter restriction can be written as $c^1_{t+s} \leqslant c^R$. Let φ_{t+s} be the multipliers of these constraints and γ, the multiplier of the implementability condition. Then the first order conditions are

$$u'(c^1_t) = \alpha + \gamma,$$

$$u'(c^1_{t+s}) = \frac{\alpha + \gamma + \varphi_{t+s}}{1 + \frac{\gamma}{\alpha}[1 - \rho]}, \quad s \geqslant 1.$$

If the constraint that the nominal interest rate cannot be negative is not binding, so that $\varphi_{t+s} = 0$, $s \geqslant 1$, then since $\rho < 1$, $u'(c^1_{t+s}) < u'(c^1_t)$, $s \geqslant 1$. Therefore $c^1_t < c^1_{t+s} \leqslant c^R$, $s \geqslant 1$, but, then, since $u'(c^1_{t+s}) - \alpha > 0$, $s \geqslant 0$, there are no incentives to deviate from the full commitment path with $c^1_{t+s} = c^R$, $s \geqslant 0$. Similarly, if—as it is the case—the zero bound constraint is binding, so that $c^1_{t+s} = c^R$, $s \geqslant 1$, in order to satisfy the budget constraint it must be that $c^1_t \leqslant c^R$. It follows that $c^1_t = c^R$. Since there are no incentives to deviate from period $t \geqslant 1$ on, the Ramsey policy is time consistent. □

6. Concluding remarks

The development of electronic payment systems has drastically reduced intermediation costs for the banking system, making inside money a closer substitute for outside money. Somewhat surprisingly, little attention has been paid to how those developments may affect the conduct of monetary policy. This paper sheds light on this and related issues.

We have shown that inside money competition may enhance efficiency, and that would certainly be the case if the provision of increasingly efficient inside money would compete with a fully committed central bank aiming at maximizing revenues. In this case, lower costs of producing inside money drive down inflation rates and, in the zero-cost limit, the Friedman rule is implemented. There are however two main qualifications to the view that inside–outside money competition works as standard product competition.

The first qualification is that competitive pressure may be exercised as an interplay between two forms of inefficiency; between the inefficiency of using costly produced inside money and the inefficiency generated by pursuing sequential monetary policies when there is limited commitment. This is the case when a revenue maximizer central bank cannot commit to future interest rates. As the supply of inside money becomes increasingly efficient, equilibrium inflation rates are driven down to the point where the inflationary rents supporting valued currency vanish, and the more efficient—even if more costly—inside money drives outside money out.

The second qualification is that the competitive pressure from inside money may be irrelevant when there is a benevolent government that delegates the implementation of monetary policy maintaining full commitment to fiscal policy. In this context monetary policy is efficient and time consistent. A Ramsey government chooses the Friedman rule with full commitment and, therefore, there is no disciplinary role for inside money competition. It turns out that such efficient policy is time consistent when there is commitment to fiscal policy. The time consistency of the Friedman rule results from the fact that there is no incentive to raise initial revenues, when the zero bound on interest rates does not allow for revenues to be reduced in the future. It follows that, even without commitment, there is no disciplinary role for inside money competition.

Although we do not analyze it in this paper, it should be clear that if the Ramsey solution implies an inflationary policy—for example, if seigniorage has to be collected because other taxes are not available—or if there is no commitment to a tax policy, then the Friedman rule is no longer time-consistent and inside money competition may affect equilibrium outcomes. In particular, in our economies the loss of confidence on outside money, following a deviation of the monetary authority, is characterized by a shift to a cashless economy. Since the technological inferiority of the inside money determines the welfare in the cashless economy, it follows that inside money competition would determine the sustainability of the Ramsey policy in these contexts.

Can the observed increased efficiency in the provision of currency substitutes justify the low inflation rates in most developed economies in the last two decades? Possibly, as we have seen, but then we should also be aware that the pressure for low inflation rates can threaten the value of currency. We have also learnt that low inflation rates can also be the outcome of properly designed fiscal and monetary institutions, even when monetary policy is discretionary.

For further reading

The following reference may also be of interest to the reader: Friedman, 1969.

Acknowledgements

A previous version of this paper was circulated with the title: ‘‘Electronic Money: Sustaining Low Inflation?’’. We thank Isabel Correia, Giorgia Giovanetti, Robert King, Sérgio Rebelo, Neil Wallace and participants at seminars where this work was presented for helpful comments and suggestions. We are particularly grateful to an anonymous referee, for many useful comments and suggestions. Teles is thankful for hospitality at the European University Institute (European Forum), and for the financial support of Praxis XXI. Marimon thanks the support of CREA (Generalitat de Catalunya). The opinions expressed herein do not necessarily represent those of the Federal Reserve Bank of Chicago or the Federal Reserve System.

References

Abreu, D., 1988. On the theory of infinitely repeated games with discounting. Econometrica 56, 383–396.

Atkinson, A.B., Stiglitz, J.E., 1972. The structure of indirect taxation and economic efficiency. Journal of Public Economics 1, 97–111.

Calvo, G., 1978. On the time consistency of optimal policy in a monetary economy. Econometrica 46, 1411–1428.

Chari, V.V., Kehoe, P., 1990. Sustainable plans. Journal of Political Economy 98, 783–802.

Chari, V.V., Christiano, L.J., Kehoe, P.J., 1996. Optimality of the Friedman rule in economies with distorting taxes. Journal of Monetary Economics 37, 203–223.

Drèze, J.H., Polemarchakis, H.M., 2000. Monetary equilibria. Mimeo, Core, Université Catholique de Louvain.

Friedman, M., 1969. The optimum quantity of money. In: Friedman, M. (Ed.), The Optimum Quantity of Money and Other Essays. Aldine, Chicago, IL.

Humphrey, D.B., Pulley, L.B., Vesala, J.M., 1996. Cash, paper, and electronic payments: a cross-country analysis. Journal of Money, Credit and Banking 28, 914–939.

Humphrey, D.B., Willesson, M., Bergendahl, G., Lindblom, T., 2003. Cost savings from electronic payments and ATMs in Europe. Mimeo, Florida State University.

Klein, B., 1974. The competitive supply of money. Journal of Money, Credit and Banking 6 (4), 423–453.

Lucas Jr., R.E., Stokey, N.L., 1983. Optimal fiscal and monetary policy in an economy without capital. Journal of Monetary Economics 12, 55–93.

Marimon, R., Nicolini, J.P., Teles, P., 2000. Competition and reputation. Mimeo, Federal Reserve Bank of Chicago.

Nicolini, J.P., 1998. More on the time consistency of optimal monetary policy. Journal of Monetary Economics 41, 333–350.

Svensson, L.E.O., 1985. Money and asset prices in a cash-in-advance economy. Journal of Political Economy 93, 919–944.

Taub, B., 1985. Private fiat money with many suppliers. Journal of Monetary Economics 16, 195–208.

Woodford, M., 1998. Doing without money: controlling inflation in a post-monetary world. Review of Economic Dynamics 1, 173–219.