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The Redistributive Effects of Inflation: an International Perspective*

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Abstract

We investigate the redistributive effects of expected inflation using a microfounded monetary model where agents differ in their degree of patience and consumption risk. Money is essential, but agents can insure against consumption risk also with bonds that offer some degree of inflation protection and that are traded in financial markets with limited participation. As long as the extent of disparities in discount factors is limited, agents hold both assets in equilibrium though in different quantities according to their type. The model is then calibrated using harmonized microdata from the *Luxembourg Wealth Study* for a subsample of OECD countries. We find inflation does not necessarily act as a regressive tax. Indeed, the magnitude and even the direction of inflation's redistributive effects depend not only on wealth distribution, but also on bonds' real returns and liquidity, in turn affected by the share of monetary trade.

Keywords: Money, Heterogeneity, Calibration, Welfare Cost of Inflation

JEL codes: E4, E5

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1 Introduction

What are the welfare costs induced by inflation? This has been a classic question in monetary economics ever since Bailey (1956). The consensus is that expected inflation and aggregate welfare are negatively correlated, but few studies so far have investigated inflation's redistributive effects. Among them, Boel and Camera (2009) develop a microfounded model of money to show that when money is the only asset, a faster rate of monetary expansion acts as a progressive tax that lowers wealth inequality. When an additional nominal asset can be traded, inflation acts as a regressive tax instead.[1] These findings share similarities with the cash/credit models in Erosa and Ventura (2002) and Albanesi (2007), and the one with incomplete markets in Camera and Chien (2014). Such results suggest that the welfare effects of expected inflation for different segments of society depend on composition and distribution of wealth, both of which vary substantially across countries.[2] These cross-country differences, however, have been overlooked by the literature so far and the focus has been on the United States.

We take a step towards filling this gap in the literature by quantifying the redistributive effects of inflation in a sample of OECD countries. We do so using a microfounded monetary model where agents can insure against consumption risk with money and one-period nominal bonds that provide some degree of inflation protection and that are traded in financial markets with limited participation. The model builds on Boel and Camera (2009), but extends it to allow for heterogeneity in time preferences. We find that as long as the extent of disparities in discount factors is limited, agents hold both assets in equilibrium. Thus, we depart from Boel and Camera (2009) where the asset distribution is degenerate, with rich agents holding only bonds and poor ones only money. This is relevant because, in that environment, there is no parameter configuration that can deliver a progressive inflation tax since it is levied solely on poor agents, as by construction they are the only ones holding money. The calibration exercise becomes more meaningful in our case, as parameter values could potentially have an effect not only on the magnitude but also on the direction of

[1] In other microfounded models of money, Chiu and Molico (2010) and Chiu and Molico (2011) investigate the redistributive effects of inflation in economies where money is the only asset.

[2] See for example Wolff (1996) and Jantti et al. (2008).

inflation's redistributive effects, given that in equilibrium all agents hold a diversified savings portfolio.

To investigate this issue, we calibrate our model for a sample of OECD countries that participate in the *Luxembourg Wealth Study* (LWS). In order to do so, we address two quantitative issues. First, we pin down money demand carefully. This is important since the welfare cost of inflation is defined as the area under the money demand curve that is lost as steady-state inflation increases, as in Bailey (1956). Given the extensive research concerned with the stability of money demand,[3] this implies accounting for the possibility of structural breaks. We show that this approach improves the quality of the fit when compared to the representative-agent study in Boel and Camera (2011), where the model actually failed to fit the data for some countries.

Second, we account for differences in wealth distribution across countries. Such comparisons have been unreliable in the past since estimates of personal wealth are sensitive to the choice of the data source, the definition of wealth and accounting conventions, all of which vary across countries. We overcome this limitation by using microdata from the LWS, an international project that has collected household microdatabases as well as standardized the wealth concept and sampling frame for a sample of OECD countries. For all countries considered, namely Austria, Canada, Finland, Italy, Japan, Norway, the United Kingdom and the United States, we find that the share of household financial wealth held in liquidity (deposit accounts) decreases with income. Countries differ substantially in terms of the magnitude of that share however, which one would expect to have important implications for the redistributive effects of inflation.

Our calibrated model provides evidence of cross-country differences in terms of both magnitude and sign of inflation's welfare effects for different segments of society. Inflation acts as a regressive tax in most countries considered, with rich agents even benefiting from inflation, but not in all. The lesson here is that inflation is not necessarily regressive simply because rich agents hold more bonds in equilibrium. Indeed, inflation's redistributive effects depend not only on wealth distribution but also, and importantly, on bonds' real returns and liquidity, in turn affected by inflation, discount rates and the share of monetary trade.

[3]For a recent literature survey, see Sriram (2001).

If liquidity and returns are low enough, then inflation can have progressive effects since rich agents still hold money in their portfolios.

The remainder of the paper is organized as follows. Section 2 describes the model, Section 3 studies the stationary monetary equilibrium, Section 4 discusses the quantitative performance of the model and Section 5 concludes.

2 The model

The model builds on Lagos and Wright (2005) and Boel and Camera (2006, 2009). Time is discrete, the horizon is infinite and there is a large population of infinitely-lived agents who consume perishable goods and discount only across periods. In each period agents may visit two sequential rounds of trade, which differ in terms of economic activities and preferences—we will refer to the first round as market one and the second as market two. In market one, agents face an idiosyncratic trading risk such that they either consume, produce, or are idle. Everyone can consume and produce in market two. Both markets are competitive.

We assume the population is divided into two types $j = H, L$ in proportions ρ and $1 - \rho$, respectively. Agents differ in two dimensions. First, in their degree of patience. Let $0 < \beta_L < \beta_H < 1$ so that we refer to type L as patient and type H as impatient. Second, in market-one trading shocks, with production and consumption being equally likely. Let $\alpha_j \in (0, 1]$ denote the probability of trading in market one for any type j agent, with $j = H, L$. Key notation is as follows. In market two of each period, an agent of type j consumes $q_j \geq 0$ goods and supplies $x_j \geq 0$ labor (equivalently, produces x_j goods), thus deriving utility $U(q_j) - x_j$. In market one, consumers of type j derive utility $u(c_j)$ from $c_j \geq 0$ consumption and all producers suffer the same linear disutility y_j from producing y_j goods. The functions u, ϕ and U satisfy the standard Inada conditions and $u(0) = U(0) = 0$. A star denotes the quantities that uniquely solve $u'(c) = 1$ and $U'(q) = 1$.

As is standard in this literature, the selected preference structure generates a single-coincidence problem in market one since consumers cannot produce. Moreover, two additional frictions characterize market one. First, agents are anonymous as in Kocherlakota (1998), since markets include agents who have never met before as in Aliprantis et al. (2006)

and thus trading histories of agents in the goods markets are private information. Second, there is no public communication of individual trading outcomes, thus eliminating the use of social punishments to support gift-giving equilibria. These two frictions together with the single-coincidence problem imply that sellers require immediate compensation from buyers. Thus, money is essential in this economy and there is no role for private credit.

2.1 Assets

Agents are price takers. The government is the only supplier of fiat money, of which there is an initial stock $\bar{M} > 0$ and which grows deterministically at a constant gross rate π via lump-sum transfers at the beginning of market two.

In market two agents of type can buy consumption insurance from an intermediary selling one-period nominal bonds at price ψ. Bonds can only be redeemed in the following market one for claims to money, which are enforceable in market two and are financed with the revenue from asset sales. The intermediary earns zero profits and operates at zero resource cost. We assume a form of limited participation in the financial sector in market one. Specifically, trade frictions affect financial markets also, thus implying idle agents in market one can access neither goods nor financial markets and so cannot redeem the asset. Market one buyers can redeem the asset and spend its claims on consumption. Market one sellers can redeem the asset and then cash its claims in the next market two. Given the heterogeneity assumed, this form of limited participation affects agents of type $j = H, L$ differently.

3 Stationary monetary allocations

We focus on stationary monetary outcomes such that both consumption and the stocks of money and bonds have constant real value. Due to stationarity, we simplify notation omitting t subscripts and use a prime superscript to identify next-period variables. We let p_1 and p_2 denote the nominal price of goods in market one and two of an arbitrary period t. We work with real variables and thus we normalize all nominal variables by p_2, so that market-one trades occur at real price $p = p_1/p_2$.

The timing of events during period t is as follows. An arbitrary agent of type j enters period t with a portfolio $\omega_j \equiv m_j + a_j$ including real holdings of money $m_j \geq 0$ and bonds $a_j \geq 0$ carried over from the previous period. Then, the idiosyncratic trading shock is realized and non-idle agents can participate in financial markets and redeem the bond. Subsequently, trade occurs and after market one closes the agent enters market two with $m_{j,k}$ where $k = n, s, b$ denotes the trading shock experienced in market one. Here, n identifies an agent who was idle, while b and s identify a buyer and a seller, respectively. Thus, money holdings evolve within the period as follows:

$$m_{j,b} = m_j + a_j - pc_j, \;\; m_{j,s} = m_j + a_j + py_j, \;\; m_{j,n} = m_j \tag{1}$$

That is, buyers deplete their balances by pc_j while sellers increase them by py_j. Cash left over is used to trade in market two, when the real price is one, q_j is consumption bought and $x_{j,k}$ is production sold by an agent who experienced shock k in market one. In market two, agents also choose their savings. Let $m'_j \geq 0$ and $a'_j \geq 0$ denote the real values of the agent's money and bond holdings at the start of next period.

In a stationary economy real asset holdings must be constant, i.e., $(m'_j, a'_j) = (m_j, a_j)$. If M is cash at the start of a cycle and $M' = \pi M$ is cash available in market two, then:

$$\frac{p'_2}{p_2} = \frac{M'}{M} = \pi \tag{2}$$

i.e., in a stationary economy aggregate real balances are constant so the inflation rate equals the rate of growth of money. This rate is controlled by means of per capita lump-sum transfers τ in market two, so the government budget constraint is:

$$\tau = [\rho m_H + (1-\rho) m_L](\pi - 1) \tag{3}$$

3.1 Market two

Given the recursive nature of the problem, we use a dynamic programming approach to describe the problem faced by the representative agent of type j in any period. We let $V_j(\omega_j)$ be the expected lifetime utility of this agent when she starts period t with a portfolio

ω_j, before trading shocks are realized. We also let $W_j(m_{j,k})$ be the expected lifetime utility from entering market two with $m_{j,k}$.

The agent's problem at the start of market two is:

$$\begin{aligned} W_j(m_{j,k}) = & \max_{q_j, x_{j,k}, m'_j \geq 0, a'_j \geq 0} [U(q_j) - x_{j,k} + \beta_j V_j(\omega'_j)] \\ \text{s.t.} & \quad x_{j,k} = q_j + \pi(m'_j + \psi a'_j) - (m_{j,k} + \tau) \end{aligned} \tag{4}$$

The resources available to the agent in market two partly depend on the realization of the trading shock k, as she has carries over $m_{j,k}$ real balances from market one. Other resources are $x_{j,k}$ receipts from current sales of goods and the lump-sum transfer τ. These resources can be used to finance current consumption q_j, to buy $\pi a'_j$ bonds at price ψ, or simply to carry $\pi m'_j$ real money balances into tomorrow's markets. The factor π multiplies a'_j and m'_j because the budget constraint lists current real values. Note that the most patient cannot lend to the less patient because the structure of the environment precludes all future direct and indirect links among current trade partners, as per Aliprantis et al. (2006).

Substituting $x_{j,k}$ from the real resource constraint, (4) is rearranged as:

$$W_j(m_{j,k}) = \max_{q_j, m'_j \geq 0, a'_j \geq 0} \{U(q_j) - q_j - \pi(m'_j + \psi a'_j) + m_{j,k} + \tau + \beta_j V_j(\omega'_j)\} \tag{5}$$

It follows that in a stationary monetary economy:

$$\frac{\partial W_j(m_{j,k})}{\partial m_{j,k}} = 1 \quad \text{for } j = H, L \tag{6}$$

The result depends on the linearity of production disutility and the use of competitive pricing. The economic implication is the marginal valuation of real balances does not depend on the agent's type j, wealth $m_{j,k}$ or trade shock k.

The model allows us to disentangle the agents' portfolio choices from their trading histories since:

$$W_j(m_{j,k}) = \quad W_j(0) + m_{j,k} \tag{7}$$

i.e., the agent's expected value from having $m_{j,k}$ at the start of a period t is the expected value from having no wealth $W_j(0)$, plus the current real value of wealth $m_{j,k}$. This implies agents of identical type exit market two with identical portfolios ω'_j independent of their histories, just as in Lagos and Wright (2005). However, different types might choose different portfolios, as we demonstrate next. By (5) we also have:

$$q_j = q^* \quad \text{for } j = H, L. \tag{8}$$

That is, everyone consumes the same amount q^* independent of her money holdings. The reason is agents in market two can produce any amount at constant marginal cost. Thus goods market clearing in market two requires:

$$q^* = \quad (1-\rho)[\tfrac{\alpha_L}{2}(x_{L,s} + x_{L,b}) + (1-\alpha_L)x_{L,n}] + \rho[\tfrac{\alpha_H}{2}(x_{H,s} + x_{H,b}) + (1-\alpha_H)x_{H,n}] \tag{9}$$

Given (8) we write:

$$W_j(m_{j,k}) = U(q^*) - q^* + m_{j,k} + \tau + \max_{m'_j \geq 0, a'_j \geq 0} [-\pi(m'_j + \psi a'_j) + \beta_j V_j(\omega'_j)]$$

The central implication is the agents' lifetime utility hinges on the trades that take place in market one, which in turn depend on the availability of financial resources and therefore agents' portfolio decisions. We investigate this next.

The first order conditions from the optimal portfolio choice are:

$$\begin{aligned} 1 &\geq \frac{\beta_j}{\pi} \times \frac{\partial V_j(\omega'_j)}{\partial m'_j} \quad (= \text{if } m'_j > 0) \\ \psi &\geq \frac{\beta_j}{\pi} \times \frac{\partial V_j(\omega'_j)}{\partial a'_j} \quad (= \text{if } a'_j > 0). \end{aligned} \tag{10}$$

Recalling that one unit of real balances buys one unit of consumption, the left hand sides of the expressions simply define the marginal cost of assets. The right hand sides define the expected marginal benefit from holding the asset, either money or bonds, discounted according to time preferences and inflation.

In market two agents have also access to an intermediary selling one-period nominal bonds at price ψ. The intermediary earns zero profits and operates at zero resource cost.

Thus, the repayment constraint faced by such intermediary is:

$$\pi\psi(\rho a_H + (1-\rho)a_L) = \rho\alpha_H a_H + (1-\rho)\alpha_L a_L, \tag{11}$$

which gives the price ψ consistent with zero profits.

It is important to realize that the benefit from holding an asset in this model depends not only on the asset's yield but also on the probability of redeeming it. Indeed, since agents differ in their access to financial markets, it follows that the expected benefit of holding any asset will generally differ across types j. To see how, we must study trades in market one.

3.2 Market one

The problem faced by an arbitrary agent j who starts a period with a portfolio ω_j is:

$$\begin{aligned} V_j(\omega_j) = \quad & \tfrac{\alpha_j}{2} \max_{c_j} \left[u(c_j) + W_j(m_{j,b})\right] + \tfrac{\alpha_j}{2} \max_{y_j} \left[W_j(m_{j,s}) - y_j\right] + (1-\alpha_j)W_j(m_{j,n}) \\ \text{s.t.} \quad & pc_j \leq m_j + a_j \end{aligned} \tag{12}$$

The agent maximizes her expected lifetime utility by choosing consumption $c_j \geq 0$ as a buyer and production $y_j \geq 0$ as a seller. From (12) we see that since buyers can redeem bonds their consumption c_j hinges on the available funds $m_j + a_j$ and price p. We start by discussing the latter. To do so, consider a seller's problem:

$$\max_{y_j} [\, W_j(m_{j,s}) - y_j]$$

Given (1) and (7), the seller's problem is linear in y_j since:

$$W_j(m_{j,s}) = W_j(0) + m_j + py_j + a_j$$

Hence, positive and finite work effort can arise only if prices in market one and two are identical, i.e.,

$$p = 1. \tag{13}$$

The reason is that sellers have unit marginal disutility from production in any market. Income raised in market one at price p_1 can be spent in market two at price p_2. Thus, market one sellers work infinite amounts if $\frac{p_1}{p_2} > 1$, or not at all if $\frac{p_1}{p_2} < 1$. When $p = 1$ sellers are indifferent to supplying any amount. Thus, in a stationary monetary economy (13) must hold. Without loss in generality, we work under the conjecture that sellers serve an equal share of aggregate demand. Goods market clearing then implies:

$$y_j = y = \frac{\rho\alpha_H c_H + (1-\rho)\alpha_L c_L}{\rho\alpha_H + (1-\rho)\alpha_L} \quad \text{for} \quad j = H, L \tag{14}$$

Now we determine c_j. A buyer's problem is:

$$\max_{c_j \geq 0} \quad u(c_j) + W_j(m_{j,b})$$
$$\text{s.t.} \quad c_j \leq m_j + a_j$$

Since $u'(0) = \infty$ we have $c_j > 0$. Recall from (1) that $m_{j,b}$ depends on c_j. Hence, the first-order condition is:

$$u'(c_j) + \frac{\partial W_j(m_{j,b})}{\partial m_{j,b}} \frac{\partial m_{j,b}}{\partial c_j} - \lambda_j = 0$$

where $\lambda_j \geq 0$ be the Kuhn-Tucker multiplier on the buyer's budget constraint. Using (6), $\frac{\partial m_{j,b}}{\partial c_j} = -p$ from (1), and (13), we have:

$$u'(c_j) = 1 + \lambda_j \tag{15}$$

If $\lambda_j = 0$, then $c_j = c^*$ since $u'(c_j) = 1$. Otherwise, $c_j < c^*$.

We can now provide a definition of equilibrium.

Definition 1. *Given an initial money stock $\bar{M} > 0$ and a government policy as specified by (π, τ), a competitive stationary monetary equilibrium is a constant list of real quantities $(c_j, y_j, q_j, x_{j,k}, m_j, a_j)$ and prices (p, ψ) that solve the agents' problems (4) and (12), satisfy (13), the financial intermediary problem* (11)*, the government budget constraint (3) and market clearing (9) and (14).*

To find the optimal portfolio of an agent we must calculate the expected marginal values of each asset, $\frac{\partial V_j}{\partial m_j}$ and $\frac{\partial V_j}{\partial a_j}$. To do so, use (1) and (7) in $V_j(\omega_j)$. We have:

$$V_j(\omega_j) = m_j + \alpha_j a_j + \tfrac{\alpha_j}{2}[u(c_j) - c_j] + W_j(0) \tag{16}$$

where c_j satisfies (15). Expression (16) tells us that the expected lifetime utility at the start of an arbitrary period depends on the agent's available balances $m_j + \alpha_j a_j$, which in turn depend on the probability of redeeming the bond, and two additional elements. First, the expected utility from trade in market one. With probability $\frac{\alpha_j}{2}$ the agent spends c_j of his wealth on consumption and gets net utility $u(c_j) - c_j$. Second, there is the continuation payoff $W_j(0)$. Hence, we have:

$$\frac{\partial V_j(\omega_j)}{\partial m_j} = 1 + \frac{\alpha_j}{2}[u'(c_j) - 1]\frac{\partial c_j}{\partial m_j} \tag{17}$$

and

$$\frac{\partial V_j(\omega_j)}{\partial a_j} = \alpha_j + \frac{\alpha_j}{2}[u'(c_j) - 1]\frac{\partial c_j}{\partial a_j} \tag{18}$$

where $\frac{\partial c_j}{\partial m_j} = \frac{\partial c_j}{\partial a_j} = 1$ if the agent is cash constrained and zero otherwise, from (15).

Of course, if assets finance consumption in market one we must also account for marginal consumption utility. Using (2), (10), (17) and (18), the agents' optimal portfolio choices must satisfy:

$$1 \geq \frac{\beta_j}{\pi}\left\{1 + \frac{\alpha_j}{2}[u'(c_j) - 1]\right\} \quad (= \text{if } m_j > 0) \tag{19}$$

$$1 \geq \frac{\beta_j}{\pi\psi}\left\{\alpha_j + \frac{\alpha_j}{2}[u'(c_j) - 1]\right\} (= \text{if } a_j > 0) \tag{20}$$

i.e., the marginal cost must be no less than the discounted expected marginal benefit.

The expressions in (17) and (18) indicate that the composition of portfolios depends on the real interest rate and on the probability of redeeming the bond. Specifically, (17) tells us that in choosing real balances the agent evaluates three components: first, the discount factor β_j; second, the real yield on cash $\frac{1}{\pi}$; and third $1 + \frac{\alpha_j}{2}[u'(c_j) - 1]$, which can be interpreted as the expected liquidity premium from having cash available in market one and it arises because money is needed to trade in that market. This premium grows with the severity of the cash constraint and the likelihood of a consumption shock.

A similar interpretation applies to the choice of bonds, with two key differences. First, bonds have a possibly higher real yield $\frac{1}{\pi\psi}$. Second, bonds have a smaller liquidity premium $\alpha_j + \frac{\alpha_j}{2}[u'(c_j) - 1]$ relative to cash since they can be redeemed only with a probability $\alpha_j < 1$. Agents consider this trade-off between bonds' illiquidity and superior return in choosing their portfolios. A central observation here is that bonds are valued dissimilarly in the economy. Indeed, the heterogeneity in access to financial markets, governed by α_j, induces heterogeneity in expected rates of return.

To understand agents' portfolio choices first of all we must take into account that in any stationary monetary equilibrium we must have $\pi \geq \beta_H$, as per Boel and Camera (2006). Thus, the rate of return on money $\frac{1}{\pi}$ cannot be excessive in a stationary monetary equilibrium. Intuitively, if $\frac{1}{\pi} > \frac{1}{\beta_H}$ then cash pays such a good return that a patient agent would want to keep accumulating money, which cannot be a stationary equilibrium.

Given this constraint on the return on money, we want to understand if agents are willing to hold both money and bonds in equlilibrium.

Proposition 1. *If $\beta_H/\beta_L = (1 - \alpha_L)/(1 - \alpha_H)$, then $m_j > 0$ and $a_j > 0$ for $j = H, L$ in a stationary monetary equilibrium.*

Proof. If $m_j > 0$ and $a_j > 0$ for $j = H, L$, then both (19) and (20) must hold with equality for $j = H, L$. If we combine (19) and (20) for $j = L$ we have that $\pi/\beta_L - 1 = \psi\pi/\beta_L - \alpha_L$. Similarly, if we combine (19) and (20) for $j = H$ we have that $\pi/\beta_H - 1 = \psi\pi/\beta_H - \alpha_H$. This implies for both conditions to hold we need $\beta_H/\beta_L = (1 - \alpha_L)/(1 - \alpha_H)$.■

Thus, in order for money and bonds to coexist in equilibrium, the difference in discount factors cannot be too large. Moreover, it must be that $\alpha_H > \alpha_L$, so that more patient agents are more active traders. Note also that, since from (19) and (20) $\psi = 1 - \beta_L(1 - \alpha_L)/\pi$ (or equivalently $\psi = 1 - \beta_H(1 - \alpha_H)/\pi$) then the price of the bond decreases if inflation increases and therefore bonds, unlike money, provide some form of inflation protection.

Summing up, monetary policy affects the expected returns of money and bonds differently, which in turn influence agents' portfolio choices and thus their exposure to the inflation tax. We investigate this quantitatively next.

4 Quantitative analysis

In this section we calibrate the model for a subsample of OECD countries that participate in the *Luxembourg Wealth Survey* (LWS), namely Austria, Canada, Finland, Italy, Japan, Norway, the United Kingdom and the United States.[4] The LWS constitutes the first cross-country wealth database in existence and it provides harmonized microdata for deposit accounts holdings, financial assets holdings and disposable income, all of which are necessary to calibrate the model's parameters. We then use the calibrated values to quantify the redistributive effects of inflation. We start by focusing on a representative-agent version of the model—this is done in order to determine the value of the preference parameters common across agents. We subsequently reintroduce heterogeneity to study the welfare impact of inflation for different segments of society. Throughout, we report the welfare cost of ten percent annual inflation as a comparison to an economy with no inflation. Data is quarterly and data sources are described in the Appendix.

4.1 Representative agent and calibration of common parameters

In the representative agent model $\alpha_j = \alpha$ and $\beta_j = \beta$ for $j = H, L$. We consider standard functional forms: $u(c) = \frac{c^{1-\eta}-1}{1-\eta}$ with $\eta > 0$ and $U(q) = A\ln(q)$ which implies $q^* = A$.[5] We set $\eta = 1$ and a quarterly discount factor $\beta = 0.9898$ consistent with an annual $\beta = 0.96$, so that preferences are homogeneous across all countries. In a monetary equilibrium the relative price p satisfies $p = 1$ and $c = m$ satisfies the agent's Euler equation in (19) in the case of a representative agent. Thus, we can find c as a function of the model's parameters and the nominal interest rate i: $c = \frac{\alpha}{2i+\alpha}$.

The parameters to identify are therefore α and A. First, α is set so that the theoretical interest elasticity of money demand ε_m matches its empirical counterpart, which we estimate following Goldfeld and Sichel (1990). For the functional forms selected we find $\varepsilon_m = -\frac{2i}{2i+\alpha}$,

[4] Cyprus, Germany, Luxembourg and Sweden also participate in the LWS, but they are excluded from our analysis due to lack of data availability. Specifically, data on deposit accounts are not available for Germany and Luxembourg. M1 data for Sweden are only available starting from 1998Q1 and M0 data from 1995Q2. Money-market interest rate data for Cyprus are only available starting from 1996Q1.

[5] See for example Lagos and Wright (2005) and Aruoba et al. (2011).

where i is the average nominal quarterly yield on a money-market instrument.[6]

The stability of money demand should be of concern here, as pointed out for example in Sriram (2001). That is because the welfare cost of inflation is measured as the area under the money demand curve that is lost as steady-state inflation rate increases, following Bailey (1956). Therefore, a poor fit of money demand would lead to meaningless estimates of the welfare cost of inflation. In order to address this issue, we test for money demand stability by running Chow (1960) tests on the money demand equation specified in Goldfeld and Sichel (1990). We find evidence of structural breaks for most countries, except for Austria, Finland and the United States. Dates and changes responsible for such breaks are shown in Table 1, together with the calibrated values of α for the superiods identified.

A brief explanation is in order. In Canada, a break occurs in the third quarter of 1982, which coincides with the end of the M1-targeting policy conducted by the Bank of Canada between 1975 and 1982. In Italy, it happens in the third quarter of 1994, which corresponds to the start of a new regime for the Bank of Italy. Indeed, Italy's central bank was given full independent power to set official interest rates in 1992, but it only stopped participating in government securities auctions in the summer of 1994. For Japan, we find evidence of two structural breaks, one in the first quarter of 2001 and the other in the third quarter of 2006. The first coincides with the start of the Quantitative Easing policy implemented by the Bank of Japan which reduced the overnight call rate to zero, and the second with the end of the same policy in March 2006. In Norway, the break occurs in the last quarter of 1992. In December 1992, the Norwegian krone was allowed to float after being pegged since 1986. Interest rates, which had previously increased sharply to defend the peg, decreased rapidly after the devaluation. Last, in the United Kingdom, the break is due to the end of the European Exchange Rate Mechanism (ERM) in the third quarter of 1992, which coincides with the start of an inflation targeting regime in the country.

For each subperiod identified, we then determine A to fit the real balances-income ratio $L = \frac{M}{PY}$, where P is the nominal price level, M is money supply, and Y is real output.[7]

[6] The Euler equation for a representative agent is $\frac{\alpha}{2}\left[u'(m/p) - 1\right] - i = 0$. Using the implicit function theorem, market clearing $c = y$ and $p = 1$ from the seller's problem, the elasticity of money demand is $\varepsilon_m = 2i/\alpha c u''(c)$. Given the functional form $u(c) = ln(c)$ and (19), we have that $c = \alpha/(2i + \alpha)$ and the expression for elasticity becomes $\varepsilon_m = -2i/(2i + \alpha)$.

[7] The United Kingdom is the only country for which M0 is used as a measure of money supply due to lack

As explained in Lagos and Wright (2005), this relationship can be interpreted as money demand in the sense that the desired real balances M/P are proportional to Y, with a factor of proportionality L that depends on the opportunity cost of holding cash, i. The theoretical expression for L in the model is $L = \frac{m}{\frac{\alpha}{2}pc+A}$.[8] Since $c = m$ in a representative agent model, given the functional forms selected the theoretical money demand becomes $L = \frac{c}{\alpha c/2+A}$. We calibrate A by minimizing the distance between L in the data and in the model, given the calibrated α. Calibrated values are in Table 1 and Figure 1 shows the quality of the fit of the model to the data. Table A1 and Figure A1 in the Appendix provide information for the case when no possibility of structural breaks is considered.

Table 1: Money demand structural breaks dates and calibrated parameters.

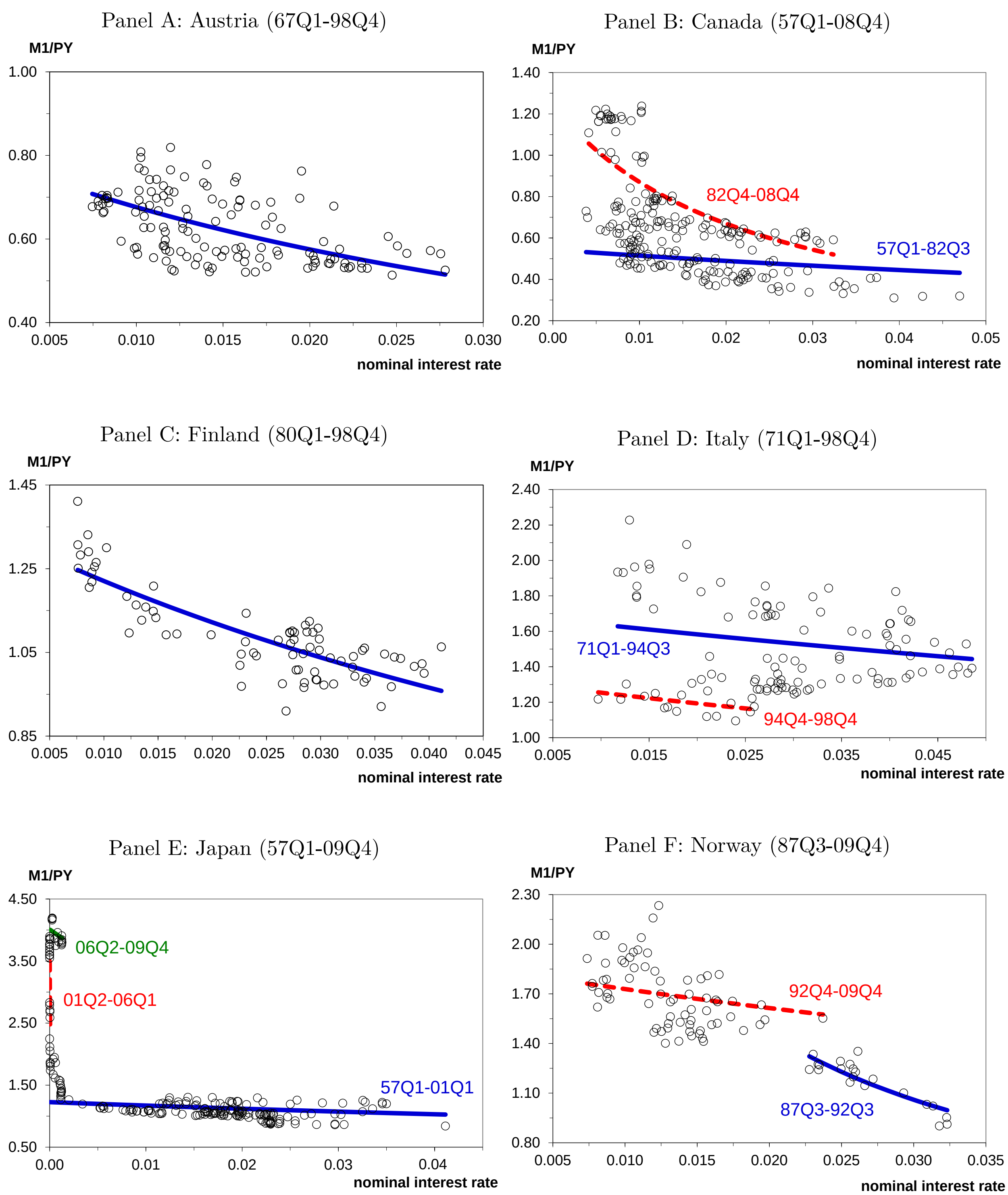
Country	Quarters	Break Explanation	ε_m	α	A	R^2
Austria	67Q1-98Q4	No break	-0.248	0.09	1.17	0.26
Canada	57Q1-82Q3	M1 target end	-0.087	0.33	1.68	0.27
	82Q4-08Q4		-0.402	0.05	0.78	0.66
Finland	80Q1-98Q4	No break	-0.212	0.18	0.66	0.70
Italy	71Q1-94Q3	CB Independence	-0.141	0.38	0.40	0.14
	94Q4-98Q4		-0.113	0.30	0.61	0.13
Japan	57Q1-01Q1	QE start	-0.089	0.33	0.65	0.24
	01Q2-06Q1	QE end	-0.103	0.00	0.28	0.54
	06Q2-09Q4		-0.024	0.06	0.22	0.33
Norway	87Q3-92Q3	Krone devaluation	-0.812	0.01	0.16	0.79
	92Q4-09Q4		-0.110	0.21	0.43	0.17
UK	69Q2-92Q3	ERM crisis	-1.219	0.01	0.89	0.21
	92Q4-06Q1		-0.096	0.24	6.86	0.42
US	59Q1-09Q4	No break	-0.191	0.11	1.07	0.37

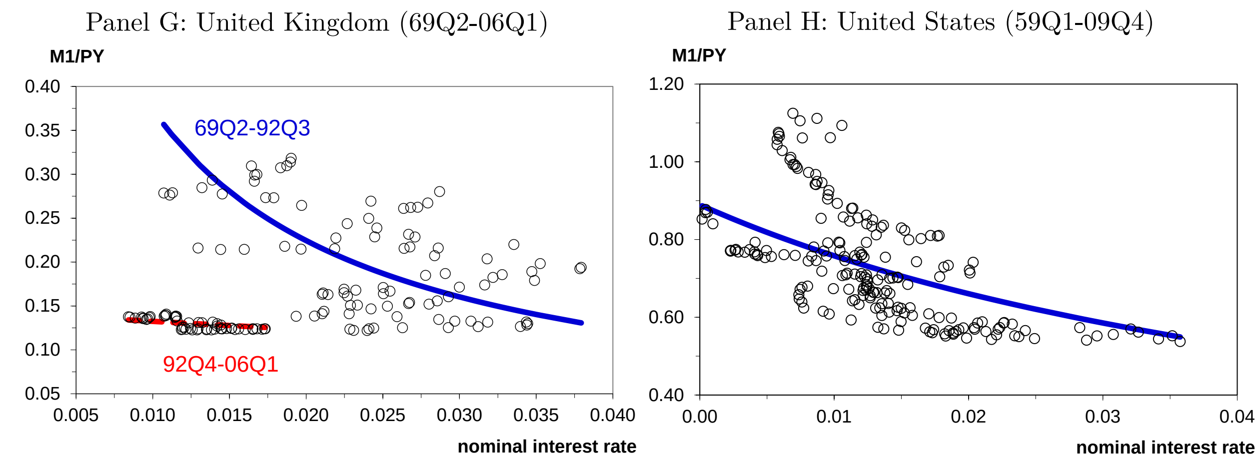
Notes: ε_m is the estimated interest elasticity of money demand. For the UK, M0 was used as the money supply measure, instead of M1. Structural breaks in money demand are identified conducting Chow (1960) tests on the regression for money demand specified in Goldfeld and Sichel (1990). No evidence of structural breaks is found for Austria, Finland and the United States. For Canada, Italy, Japan and Norway the Chow test is significant at the 1% level and for the UK at the 5% level. The exact value of α for Japan in the period 01Q2-06Q1 is 0.0002.

of data availability for M1.

[8]Note that $\frac{\alpha}{2}pc + A$ is the sum of output in the first and second market.

Figure 1: Money Demand with Fitted Model and Structural Breaks





Notes for Figure 1: for each country, circles identify empirical money demand M/PY against the nominal interest rate for each quarter in the sample period. The solid lines identify the calibrated money demand. Different subperiods are identified when structural breaks in money demand occur.

For each country considered, we then recalibrate the parameters α and A for the entire period as the weighted average of α and A for the subperiods listed in Table 1. This allows us to pin down parameter values for the full period while still accounting for how α and A changed over time. The calibrated parameters, which are listed in Table 2, are then used to quantify the welfare cost of inflation for the representative agent. The definition is standard and it follows the one in Lucas (2000). Thus, it should be interpreted as the percentage adjustment in consumption (in both markets) the representative agent would require in order to be indifferent between a steady state with gross inflation rate π and a lower inflation rate $z \in [\beta, \pi)$. Fixing π, equilibrium ex-ante welfare is:

$$(1-\beta)V_\pi = \frac{\alpha}{2}[u(\bar{\Delta}_\pi c_\pi) - \phi(c_\pi)] + U(\bar{\Delta}_\pi q^*) - q^* \tag{21}$$

If we reduce π to z and adjust consumption in both markets by the proportion $\bar{\Delta}_z$, then:

$$(1-\beta)V_z = \frac{\alpha}{2}[u(\bar{\Delta}_z c_z) - \phi(c_z)] + U(\bar{\Delta}_z q^*) - q^* \tag{22}$$

The welfare cost of having π instead of z inflation is the value $\Delta_z = 1 - \bar{\Delta}_z$ such that $V_\pi = V_z$, where V_π and V_z are defined in (21) and (22) respectively. If $\Delta_z > 0$, agents are indifferent between π inflation, or alternatively z inflation and consumption reduced by Δ_z percent. Values for the different countries are shown in Table 2.

4.2 Heterogeneity and redistribution

In order to measure the redistributive effects of inflation we proceed as follows. First, we fix the common preference parameters (η, α, β, A) to the values calibrated for the representative-agent model. We then set the average trading friction and discount factor to the values α and β respectively from the representative-agent model and we consider mean preserving spreads such that $\rho\alpha_H + (1-\rho)\alpha_L = \alpha$ and $\rho\beta_H + (1-\rho)\beta_L = \beta$ for some given value ρ. We associate $j = H$ to the top two income quintiles so that $\rho = 0.4$. We fix the discount factor for the most patient to the highest possible value $\beta_H = 0.\overline{9}$, which implies $\beta_L = 0.983$, still consistent with the empirical evidence on discount factors provided in Lawrence (1991), Carroll and Samwick (1997) and Samwick (1998). This, together with the condition $\beta_H/\beta_L = (1-\alpha_L)/(1-\alpha_H)$ from Proposition 1, allows us to pin down the remaining parameters α_L and α_H, the values for which are shown in Table 2.

In order to solve for the endogenous variables in the model, we proceed as follows. We use (8), (19), (20), the budget constraint $c_j = m_j + a_j$, (11) and the calibrated share $s_j = m_j/(m_j + a_j)$ to pin down A, ψ, m_j and a_j for $j = H, L$. Note s_H and s_L are calibrated from the LWS[9] as the share of deposit accounts, which we use as a proxy for liquidity, over total financial assets[10] of the top 40% and bottom 60% of the disposable income distribution respectively.[11] As reported in Table 2, s_j decreases with income for all countries considered, even though its magnitude varies across countries. Japan stands out as the only exception, since the ratio stays pretty much constant across income quintiles. This is consistent with the evidence in Nakagawa and Yasui (2009), who note that the average Japanese household has a financial balance sheet that is far more conservative than in other industrialized countries.

[9]For the countries where LWS microdata are available for more than one year, data should be interpreted as averages across all years available. Data availability is as follows: Austria (2002), Canada (1999), Finland (1994 and 1998), Italy (2002 and 2004), Japan (2003), Norway (2002), United Kingdom (2000), United States (1994, 1997, 2000, 2003 and 2006).

[10]Deposit accounts (DA) include transaction accounts, savings accounts and term deposits or CDs (i.e. bank deposits, current account deposits, bank savings, postal bank deposits, etc.). Total financial assets (TFA1) are the sum of deposit accounts, bonds, stocks and mutual funds.

[11]We use disposable income (DPIW) instead of gross income due to data availability, since the LWS does not provide data on gross income for Austria and Italy.

Table 2: Calibrated parameters and welfare costs of inflation.

								Welfare Cost		
									Heterogeneous Case	
Country	α	A	μ	s_H	s_L	α_H	α_L	Rep. Agent	Type H	Type L
Austria	0.09	1.17	2.79	0.72	0.84	0.10	0.08	0.43	0.40	0.40
Canada	0.19	1.22	5.51	0.36	0.53	0.20	0.18	0.28	0.14	0.35
Finland	0.18	0.66	10.88	0.59	0.78	0.19	0.18	0.50	0.25	0.64
Italy	0.36	0.43	28.22	0.56	0.79	0.37	0.36	0.39	-0.09	0.68
Japan	0.28	0.58	17.92	0.85	0.88	0.29	0.28	0.39	0.34	0.40
Norway	0.16	0.37	15.12	0.62	0.83	0.17	0.16	0.89	0.44	1.12
UK	0.10	3.07	1.17	0.50	0.60	0.10	0.09	0.16	0.16	0.15
US	0.11	1.07	3.43	0.18	0.34	0.12	0.10	0.43	0.34	0.45

Notes: α and A are calculated as the weighted average of their counterparts for the subperiods listed in Table 1; μ is the share of monetary trade expressed in percentage points. For the calibration exercise, type H and L are interpreted as households belonging to the highest 40% and the lowest 60% of the income distribution respectively, so that $\rho = 0.4$, and s_H and s_L denote the shares of liquid assets over total financial assets held by type H and L agents respectively. Welfare costs are for 10% annual inflation relative to 0% inflation.

The calibrated parameters are then used to quantify the welfare cost of inflation for types H and L. Fixing π and given (3), (6), (7) and (16), ex-ante welfare for type $j = H, L$ is:

$$(1-\beta_j)V_{j,\pi}(\omega_{j,\pi}) = \frac{\alpha_j}{2}[u(c_{j,\pi}) - c_{j,\pi}] + U(q^*) - q^* + \tau_\pi - (\pi - 1)m_{j,\pi} + a_{j,\pi}(\alpha_j - \pi\psi_\pi) \quad (23)$$

There are two terms in (23) that do not appear in the representative agent version in (21). First, there is the the redistributive effect of inflation on money holdings $\tau_\pi - (\pi - 1)m_{j,\pi}$, which encompasses the lump-sum transfer minus the inflation tax. Agents with less than average money holdings will end up with a net transfer, whereas the others will pay a net tax. Second, there is the redistributive effect of inflation on bonds $a_{j,\pi}(\alpha_j - \pi\psi_\pi)$. Note that, since bonds are nominal, they are still subject to the inflation tax, but at a lower net rate $\pi\psi$ than money holdings since the bond price ψ is less than one. Note also that the bonds' return hinges on the probability α_j of redeeming it. If such probability is small, then inflation may end up having progressive effects.

If we reduce π to z and adjust consumption in both markets by the proportion $\bar{\Delta}_{j,z}$, then ex-ante welfare is defined by:

$$(1-\beta_j)V_{j,z}(\omega_{j,z}) = \frac{\alpha_j}{2}[u(\bar{\Delta}_{j,z}c_{j,z})-c_{j,z}]+U(\bar{\Delta}_{j,z}q^*)-q^*+\tau_z-(z-1)m_{j,z}+a_{j,z}(\alpha_j-z\psi_z) \quad (24)$$

Analogous to the case of a representative agent, the welfare cost of having π instead of z inflation for a type j agent is the value $\Delta_{j,z} = 1 - \bar{\Delta}_{j,z}$ that satisfies $V_{j,\pi} = V_{j,z}$, where $V_{j,\pi}$ and $V_{j,z}$ are defined in (23) and (24) respectively. If $\Delta_{j,z} > 0$, then an agent j is indifferent between π inflation, or alternatively z inflation and consumption reduced by $\Delta_{j,z}$ percent.

Values for the welfare cost of inflation for different countries are shown in Table 2. We find evidence of cross-country differences in both the magnitude and the sign of inflation's redistributive effects. Indeed, inflation acts as a regressive tax in most countries (Canada, Finland, Japan, Norway, USA), with rich agents even benefiting from inflation in others (Italy). In the UK, inflation acts as a progressive tax instead.

Such discrepancies are not explained uniquely by differences in wealth distribution. For example, inflation's effects are far more regressive in Japan, where the ratio s_j is pretty much constant across types, than in Austria, where inflation acts as a flat tax even though there is more heterogeneity in s_j. This is because inflation's redistributive effects depend also, and importantly, on bonds' net real returns $\alpha_j - \pi\psi$. If the probability α_j of redeeming a bond is low also for type H agents, that is if the bond is illiquid, then inflation can have progressive effects. Note also that the probability α_j is related to the shape of money demand. When the share of monetary trade $\mu = \frac{c\alpha/2}{c\alpha/2+A}$ is low like in the UK, where M0 is used as a measure of money supply, the probability of redeeming a bond for money is also low. The converse is true for Italy.

The lesson here is that, when thinking about inflation's redistributive effects, we should take into account not only wealth distribution, but also the real returns and the liquidity of assets alternative to money. If both returns and liquidity are low, then inflation can even have progressive effects since rich agents still hold money in their portfolios.

5 Final remarks

We quantify the redistributive effects of expected inflation using a microfounded monetary model which is based on Boel and Camera (2009), but differs from it in that agents are heterogeneous not only in consumption risk but also in their time preferences. As a consequence, whereas in Boel and Camera (2009) agents hold either money or nominal bonds in equilibrium, in our model all agents choose a differentiated savings portfolio as long as the extent of disparities in discount factors is limited.

We then calibrate the model for a set of countries participating in the *Luxembourg Wealth Study*, an international project that has collected household microdatabases from a sample of OECD countries, for which it has standardized the wealth concept and sampling frame. In doing so, we address two quantitative issues. First, we pin down money demand carefully by accounting for the possibility of structural breaks. Second, we account for differences in wealth distribution across countries by using harmonized microdata from the *Luxembourg Wealth Study*.

We find evidence of cross-country differences in terms of both the magnitude and the sign of inflation's welfare effects for different segments of society. Inflation acts as a regressive tax in most countries considered, with rich agents even benefiting from inflation, but not in all. Thus, we shouldn't think of inflation as necessarily regressive. Indeed, we find inflation's redistributive effects depend not only on wealth distribution but also, and importantly, on bonds' real returns and liquidity, in turn affected by inflation, discount rates and the share of monetary trade. If such returns and liquidity are low enough, inflation can have progressive effects given that rich agents still hold money in their portfolios.

The analysis also raises questions. In particular, one must wonder if the direction of inflation's redistributive effects may depend also on the nature of the alternative asset considered and thus if results may change in an economy with real assets or private credit. The ongoing work in Boel, Díaz and Finocchiaro (2016) investigates this issue in a microfounded model of money.

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Appendix

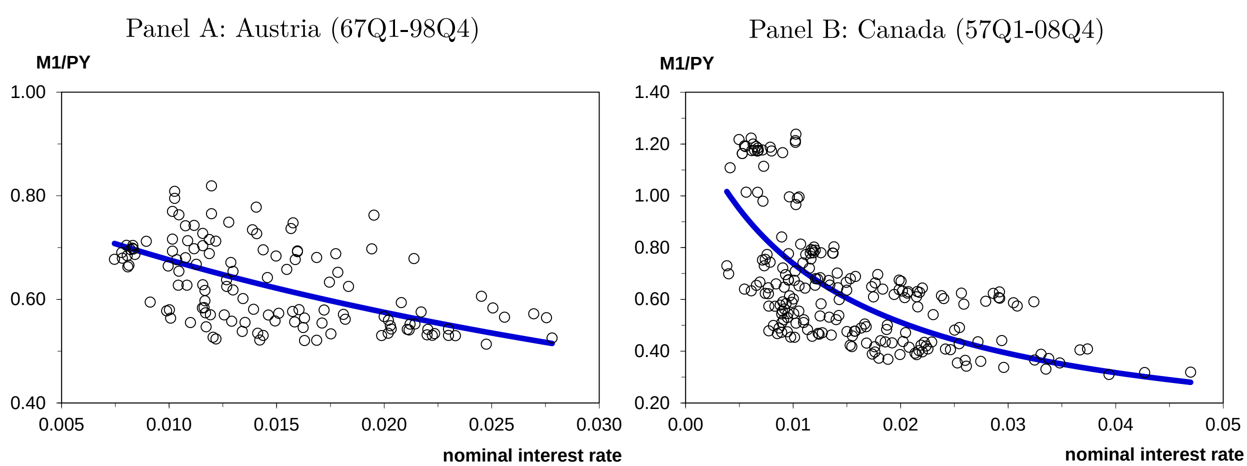
A1. Money demand fit without structural breaks

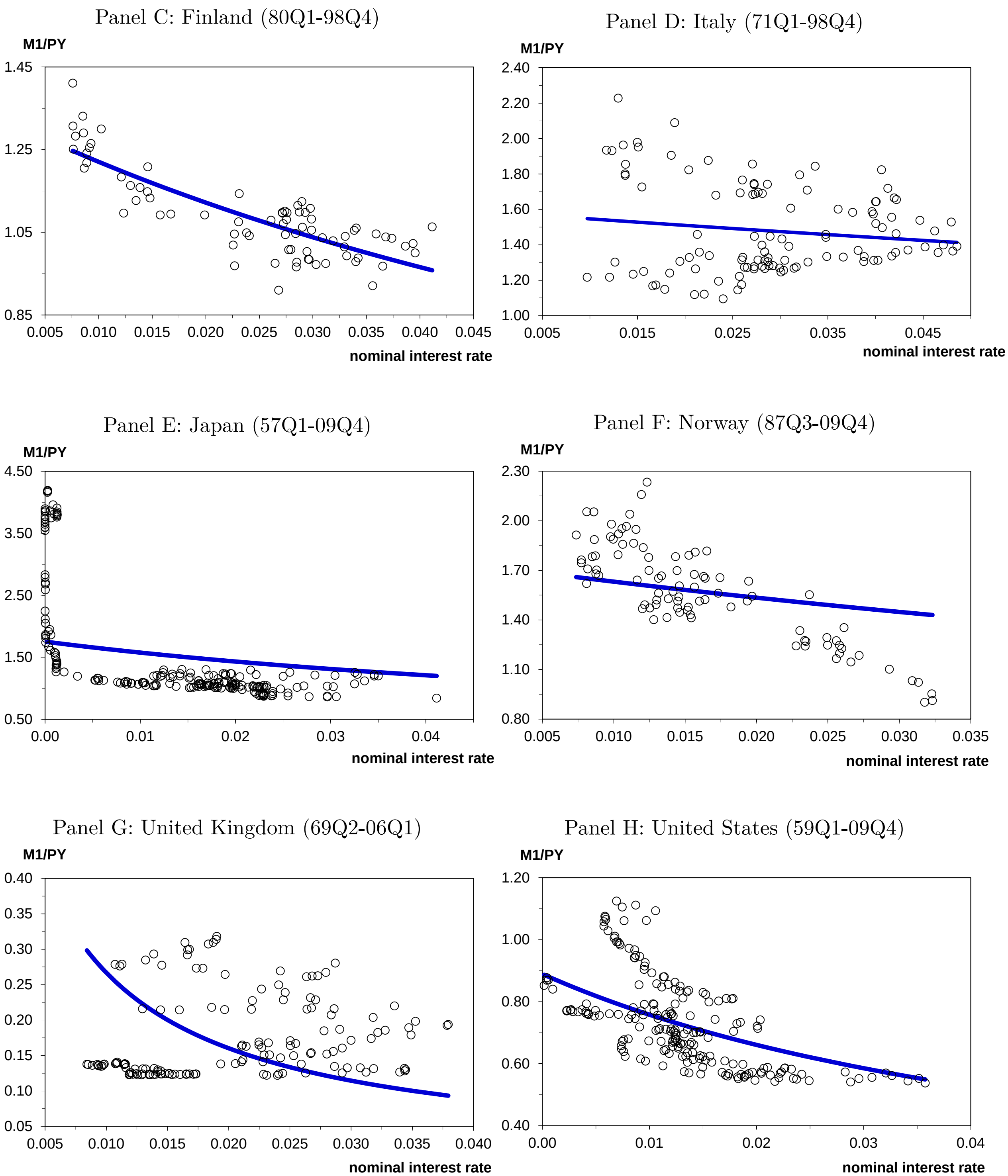
Table A1: Calibrated parameters and money demand fit (no structural breaks).

Country	Quarters	ε_m	α	A	R^2	Welfare Cost
Austria	67Q1-98Q4	-0.248	0.09	1.17	0.26	0.43
Canada	57Q1-08Q4	-0.547	0.02	0.74	0.42	0.69
Finland	80Q1-98Q4	-0.212	0.18	0.66	0.70	0.50
Italy	71Q1-98Q4	-0.106	0.49	0.39	0.02	0.32
Japan	57Q1-09Q4	-0.151	0.15	0.49	0.20	0.74
Norway	87Q3-09Q4	-0.121	0.24	0.46	0.32	0.54
UK	69Q2-06Q1	-0.998	0.01	1.24	-1.23	0.30
US	59Q1-09Q4	-0.191	0.11	1.07	0.37	0.43

Notes: ε_m is the estimated interest elasticity of money demand. For the UK, M0 was used as the money supply measure, instead of M1. Note that a negative R^2 (UK) is possible since the model is non linear. Welfare costs are for 10% annual inflation relative to 0% inflation.

Figure A1: Money Demand with Fitted Model without Structural Breaks





Notes for Figure A1: for each country, circles identify empirical money demand M/PY against the nominal interest rate for each quarter in the sample period. The solid lines identify the calibrated money demand.

A2. Data sources

Data for deposit accounts (DA), total financial assets (TFA1) and disposable income (DPIW) are from the *Luxembourg Wealth Study.* Data for money supply, interest rate, price deflator and nominal GDP are from the *International Financial Statistics* unless otherwise noted. GDP and money supply are in local currencies.

Austria (1967Q1-1998Q4). Money supply: M1 (12234); interest rate: money market rate (12260B); price deflator: GDP deflator (12299BIP); output: nominal GDP, sa (12299B).

Canada (1957Q1-2008Q4). Money supply: M1 (15634); interest rate: treasury bill rate (15660C); price deflator: GDP deflator (15699BIR); output: nominal GDP, sa (15699B).

Finland (1980Q1-1998Q4). Money supply: M1 (OECD); interest rate: money market rate (17260B); price deflator: GDP deflator (17299BIP); output: nominal GDP (17299BIP).

Italy (1971Q1-1998Q4). Money supply: Money supply: M1 (13634); interest rate: money market rate (13660B), price deflator: CPI (13664), output: nominal GDP (13699B.C).

Japan (1957Q1-2009Q4). Money supply: M1, sa (IFS, National Definition) (15859MAC); interest rate: money market rate (15860B); price deflator: GDP deflator (15899BIR); output: nominal GDP, sa (15899B.C).

Norway (1987Q3-2009Q4). Money supply: M1 (14234); interest rate: government bond yield (14261), price deflator: CPI (14264); output: nominal GDP (14299B).

United Kingdom (1969Q2-2006Q1). Money Supply: break-adjusted M0, Bank of England (LPMVUBNI); interest rate: treasury bill rate (11260C); price deflator: GDP deflator (11299BIR); output: nominal GDP, sa (11299B.C).

United States (1959Q1-2009Q4). Money supply: sweep-adjusted M1 (M1S from sweepmeasures.com, Cynamon et al., 2006); interest rate: treasury bill rate (11160C); price deflator: GDP deflator (11199BIR); output: nominal GDP, sa (11199B).

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