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Time-Varying Money Demand and Real Balance Effects*

Jonathan Benchimol[†] and Irfan Qureshi[‡]

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Abstract

This paper presents an analysis of the stimulants and consequences of money demand dynamics. By assuming that household's money holdings and consumption preferences are not separable, we demonstrate that the interest-elasticity of demand for money is a function of the household's preference to hold real balances, the extent to which these preferences are not separable in consumption and real balances, and trend inflation. An empirical study of U.S. data revealed that there was a gradual fall in the interest elasticity of money demand of approximately one-third during the 1970s due to high trend inflation. A further decline in the interest-elasticity of the demand for money was observed in the 1980s due to the changing household preferences that emerged in response to financial innovation. These developments led to a reduction in the welfare cost of inflation that subsequently explains the rise in monetary neutrality observed in the data.

Keywords: Time-varying money demand, Real balance effect, Welfare cost of inflation, Monetary neutrality.

JEL Codes: E31, E41, E52.

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1 Introduction

Since the 1980s, the long-standing empirical theories that connect several alternative monetary aggregates to movements in prices and interest rates have gradually evolved (Friedman and Kuttner, 1992). Specifically, the application of the framework proposed by Lucas (2000) led Ireland (2009) to the detection of important changes in the interest semi-elasticity of money demand in the period following the 1980s. For many decades, the monetary policy theory literature was focused on the implications of the interest-elasticity of money demand and the role this played in determining the effectiveness of monetary policies (Tobin, 1956; Laumas and Laumas, 1969; Vernon, 1977). King (1999) and Friedman (1999) confirmed the limited effectiveness of monetary policy as a consequence of a moneyless economy while the findings of Woodford (2000, 2003, 2008) contradicted this result.

Most of the debate in this domain focused on the interest semi-elasticity of money demand, which is essentially concerned with monetary neutrality (Lucas, 1996). As this long and lively debate demonstrated, the extent to which money can influence the interest rate and welfare cost of inflation could change over time. In this paper, we document and assess the causes and macroeconomic consequences of the time-varying relationship between interest rates and money. We derive a general micro-founded interpretation of the familiar log-linear money demand relationship described in Lucas (2000), which is aligned with that employed by Ireland (2009). The interest semi-elasticity of money demand is described as a function of the household's preferences to hold real balances and substitute consumption and real balances, steady-state gross inflation, and interest rates. Therefore, the expression enables us to capture the structural channels that may have stimulated the changes in the money demand observed in the empirical literature.

An application of such a micro-founded money demand framework allows the quantification of the welfare cost of inflation by linking it with the structural parameters that drive the interest semi-elasticity of money demand. The subsequent framework can pin down the parameters of interest in this equation, both through examining the first moments in the data and direct estimation.

Our empirical estimation of the money demand equation based on the quarterly U.S. data covering the period 1959 to 2008 reveals that there was a decline in the interest semi-elasticity of money demand and a subsequent fall in the welfare cost of inflation during this period. The benchmark results confirm the analysis offered by Ireland (2009), who found a semi-elasticity below 2 as well as a smaller welfare cost estimate of modest departures from Friedman's zero nominal interest rate rule for the optimum quantity of money during the post-1980s era.

Allowing for time variation in the money demand function using recursive estimates reveals a gradual fall in the interest elasticity of money demand of approximately one-third during the 1970s due to both trend inflation and an in-

crease in interest rates. A further decline in the interest-elasticity of the demand for money was observed in the 1980s due to the changing household preferences that emerged in response to financial innovation. The latter influenced the household's preferences to hold real balances and their willingness to substitute real balances and consumption. In combination, our results suggest that the entire shift in money demand could be attributed to the evolution of trend inflation, interest rates, and changes in the household's preferences, thereby explaining the results found in Ireland (2009) and Lucas (2000).

These developments led to a reduction in the welfare cost of inflation that subsequently explains the rise in monetary neutrality observed in the data. Our time-varying estimates of money demand show that the welfare cost of 10 percent inflation decreased from 0.92 percent of income in the 1960s to under 0.20 percent of income in the 1990s.¹ Since household's preferences and trend inflation enter the IS equation through various structural parameters, changes in these parameters may have broader macroeconomic consequences. A comparison of the reactions of output to an interest rate shock between pre-1979 and post-1980s periods based on a vector autoregression (VAR) indicates that the impact elasticity of monetary policy roughly halved. An interest rate shock had approximately 35% less impact on output in 1980 than it did during the pre-1979 period. The fall in the household's preferences to hold real balances and substitute between consumption and real balances altered key parameters in the IS curve. Therefore, changes that affect the traditional money demand relationships may also explain a proportion of the rise in monetary neutrality observed in the data.

This paper adds to the existing debate in multiple ways. It provides a micro-founded interpretation of the interest semi-elasticity of money demand and the welfare cost of inflation. This extends the work of many scholars (Cagan, 1956; Lucas, 1981; Meltzer, 1963; Sidrauski, 1967; Fischer, 1981; Cooley and Hansen, 1989; Dotsey and Ireland, 1996; Lucas, 2000; Ireland, 2009; Miller et al., 2019). The identification of the changes in the semi-elasticity and the welfare cost can explain the contrasting welfare estimates presented in the existing literature (Broadbuddus and Goodfriend, 1984; Reynard, 2004; Ireland, 2009; Lucas and Nicolini, 2015). Belongia and Ireland (2019) proposed alternative monetary measures that preserve these long-standing relationships and add to the theoretical explanations, such as those based on Baumol-Tobin style inventory-theoretic models of money (Atanasio et al., 2002; Alvarez and Lippi, 2009), or insurance against idiosyncratic liquidity shocks (Berentsen et al., 2015), all of which equate changes in household

¹For example, Ireland (2009) found a welfare cost for a 10% inflation rate of less than 0.25% of income. Lucas (2000) found a welfare cost for 10% inflation of just over 1.8% income. Fischer (1981) found a welfare cost for 10% inflation between 0.2% and 0.3% income. Cooley and Hansen (1989) found that a welfare cost of 10% inflation is about 0.4% of GDP using a cash-in-advance version of the business cycle model. Miller et al. (2019) found a welfare cost for 10% inflation of just over average 0.27% income.

behavior to the breakdown in money demand relationships.

The changing household's substitution preferences between consumption and real balances and the corresponding empirical results extend the existing literature on estimates of real balances through constant elasticity of substitution (CES) money-in-the-utility function (MIUF) specification (Holman, 1998; Finn et al., 1990; Poterba and Rotemberg, 1987; Benchimol and Fourçans, 2012, 2017). While Ireland (2004) and Woodford (2003) found that the weight of real balances was of a negligible size, our time-varying estimation highlights how this weight was larger during the 1960s and 1970s before falling to zero from the mid-1980s onwards. Broadly speaking, since real balances enter directly in the dynamic IS, determining inflation and output dynamics through this channel may be relevant during this period, and this finding complements that of Castelnovo (2012) and Benchimol and Fourçans (2017). This effect is combined by a higher elasticity of substitution between consumption and real balances, implying that household's preferences are not fully separable in either time period.

The findings also explain the shifts in the welfare cost of inflation and connect both the household behavior and changes in the U.S. macroeconomic dynamics through the money demand function. The time-varying aspect of the semi-elasticity contributes to the money demand instability (Khan, 1974; Judd and Scadding, 1982; Tesfatsion and Veitch, 1990; Hafer and Jansen, 1991; Miller, 1991; Lütkepohl, 1993; Chen, 2006; Ireland, 2009; Hall et al., 2009; Inagaki, 2009; Jawadi and Sousa, 2013; Lucas and Nicolini, 2015; Miller et al., 2019). These results indicate that the single-valued approach to approximating the welfare cost of inflation presented in previous literature captures only the sample average at each point in time.

The introduction of trend inflation in the model augments the interest semi-elasticity of money demand debate by enriching the model along the lines of various papers (Hornstein and Wolman, 2005; Amano et al., 2007; Ascari and Ropele, 2007; Kiley, 2007; Ascari and Ropele, 2009; Ascari and Sbordone, 2014). The rise in trend inflation is one of the primary reasons for the fall in the semi-elasticity due to the rise in the opportunity cost of holding money. By highlighting how high trend inflation affects the semi-elasticity and, therefore, the welfare cost of inflation, the outcomes of our analysis are original and provide several policy recommendations.

Finally, this paper presents an alternative channel by which it is possible to explain the decline in monetary policy effectiveness that was observed in the post-1980s period. Mallick and Mohsin (2010, 2016) found that inflation has an important permanent effect on the real economy in several ways including consumption, investment, and the current account. Our model, which also incorporates the cash-in-advance constraint (CIA), mimics these findings since it identifies trend

inflation as a key driver of real effects. However, in our framework, the transmission works through the money demand channel. Boivin and Giannoni (2002) concluded that changes in the monetary policy rule were responsible for the variations that were observed in the impulse responses. Pancrazi and Vukotic (2019) found that the decline in the effectiveness of monetary policy could be attributed to the evolution of labor market properties. Instead, we show that the changes in the household's preferences that were observed may explain a large portion of the decline in the effectiveness of monetary policy in the short-term. These changes are larger for the short-run and decline over the medium-to-long run, a result that converges with the findings of Pancrazi (2014).

The rest of the paper is structured as follows. In Section 2, we derive the money demand curve from micro-foundations that include positive trend inflation. Section 3 presents the welfare loss derivations, Section 4 discusses the empirical findings, and Section 5 studies the consequences of the money demand curve on the welfare cost of inflation and the resulting reduction in the impact of monetary policy. Section 6 concludes the paper and offers suggestions for future research. Finally, additional supporting results and data are provided in the appendix.

2 The Theoretical Framework

2.1 The Model

The economy consists of a continuum of households, in which the representative household seeks to maximize the following objective function:

$$E_0 \left[\sum_{t=0}^{\infty} \beta^t U \left(C_t, \frac{M_t}{P_t}, N_t \right) \right] \quad (1)$$

where C_t is the quantity consumed of the single good, M_t/P_t denotes holdings of real money balances and serves as a unit of account, and N_t denotes worked hours.

We consider the specific case in which the period utility is given by the following functional form:

$$U \left(C_t, \frac{M_t}{P_t}, N_t \right) = \frac{X_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} \quad (2)$$

where σ represents the relative risk aversion of households (or the inverse of the intertemporal elasticity of substitution), φ is the inverse of the elasticity of work effort with respect to the real wage (Frisch elasticity), and X_t is a composite index

of consumption and real balances defined as:

$$\begin{cases} X_t = \left[(1 - \theta) C_t^{1-v} + \theta \left(\frac{M_t}{P_t} \right)^{1-v} \right]^{\frac{1}{1-v}} & \text{for } v \neq 1 \\ X_t = C_t^{1-\theta} \left(\frac{M_t}{P_t} \right)^{\theta} & \text{for } v = 1 \end{cases} \quad (3)$$

with v representing the (inverse) elasticity of substitution between consumption and real balances, and θ the relative weight of real balances in utility, as presented in Greenwood et al. (1988).

The composite index X_t reflects the non separability property of the utility function² given the values of the parameters σ and v . The parameter θ captures the “direct effect” of money or the marginal utility of money valued at the steady-state. The parameter v , which represents the (inverse) elasticity of substitution between consumption and real balances, captures the “indirect effect” or the cross-partial derivative of money with consumption.

Changes in these parameters have very general interpretations. A variation in θ may represent shocks to transactions technology – shocks that change the utility value of money relative to that of consumption expenditures (Koenig, 1990). Thus, financial innovation that reduces transaction costs may be captured by this parameter θ . On the other hand, a variation in v captures the preference changes for a household to substitute money and consumption.³

Maximization of the objective function (Eq. 1) is subject to a sequence of flow budget constraints given by:

$$P_t C_t + Q_t B_t + M_t \leq B_{t-1} + M_{t-1} + W_t N_t - T_t \quad (4)$$

where P_t is the price of the consumption good, W_t is the nominal wage, and B_t is the quantity of one-period nominally risk-less discount bonds purchased in period t and maturing in period $t + 1$. Each bond pays one unit of money at maturity and its price is Q_t . T_t represents lump-sum additions or subtractions to period income.

Let the total financial wealth at the end of period t be defined as $\Omega_t = B_t + M_t$.

²In non separable utility functions, the marginal utility of consumption directly depends on variations of real money balances and allows us to investigate the effects of variations in real money on the economy (Benchimol, 2016). In contrast, a separable utility function leaves consumption, and the economy, indifferent to variations in real money balances (Benchimol, 2014). Under a separable utility, the equilibrium values of real variables are determined independently of real money balances and of any implemented monetary policy (Galí, 2015).

³Adding a transaction/liquidity cost, using a shopping time model (with money) or a CIA constraint, as in Mallick and Mohsin (2010, 2016), would be functionally equivalent to the MIU specification (Feenstra, 1986). In a way, these mechanisms are succinctly captured by the parameters θ and v .

The budget constraint (Eq. 4) can then be written compactly as:

$$P_t C_t + Q_t \Omega_t + (1 - Q_t) M_t \leq \Omega_{t-1} + M_{t-1} + W_t N_t - T_t \quad (5)$$

Written like Eq. 5, one readily sees the opportunity cost of investing resources in money rather than bonds. The bond price, Q_t , determines the interest rate such as $i_t = -\ln(Q_t)$, where i_t is the short-term nominal interest rate and is equal to $\rho = -\ln(\beta)$ in the steady-state.

We assume a representative firm whose technology is described by a production function given by:

$$Y_t = A_t N_t^{1-\alpha} \quad (6)$$

where A_t represents the level of technology and $a_t = \ln(A_t)$ is assumed to evolve exogenously according to some stochastic process.

Maximizing the objective function (Eq. 1) subject to the flow budget constraint (Eq. 5), the necessary first-order conditions for any t can be written as:

$$\frac{M_t}{P_t} = C_t (1 - \exp(-i_t))^{-\frac{1}{\psi}} \left(\frac{\theta}{1 - \theta} \right)^{\frac{1}{\psi}} \quad (7)$$

$$Q_t = \beta E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\psi} \left(\frac{X_{t+1}}{X_t} \right)^{\psi-\sigma} \frac{P_t}{P_{t+1}} \right] \quad (8)$$

$$N_t^\varphi X_t^{\sigma-\psi} C_t^\psi (1 - \theta)^{-1} = \frac{W_t}{P_t} \quad (9)$$

2.2 Motivation for Positive Trend Inflation

The relevant equations of the model are log-linearized around a zero-growth and non-zero inflation steady-state, which has been shown to be an important feature of the U.S. economy.⁴ In this sense, solving for the non-zero trend inflation may yield a more realistic representation of the structural model.

Under the steady-state assumptions, the Euler equation (Eq. 8) can be written as:

$$Q\Pi = \beta \quad (10)$$

where Q represents the steady-state bond prices and Π the steady-state gross in-

⁴Ascari and Sbordone (2014) construct a generalized new Keynesian model that accounts for positive trend inflation. In this model an increase in trend inflation is associated with a more volatile and unstable economy and trends to destabilize inflation expectations. Hornstein and Wolman (2005), Kiley (2007), and Ascari and Ropele (2009) show that when appropriately considered, positive trend inflation substantially alters the models' structural equations and the determinacy region. Amano et al. (2007) study how the business cycle characteristics of the model (i.e., persistence, correlation, and volatility) vary with trend inflation. Ascari and Ropele (2007) analyze how optimal short-run monetary policy changes with trend inflation.

flation. This contains straightforward economic intuition. Under zero inflation, $\Pi = 1$, the price of the bond today is exactly equal to the utility weight the household attaches to its return (which is one). The household has no incentive to save or dissave to let their marginal utility differ across periods. This return is affected by the gross inflation return.

By using Eq. 8, the steady-state money demand relationship can also be simplified such as:

$$\frac{M}{PC} = \left(\frac{\Pi\theta}{(\Pi - \beta)(1 - \theta)} \right)^{\frac{1}{v}} = \kappa_m \quad (11)$$

The expression suggests that not only does the ratio of steady-state level of money holdings with respect to consumption decrease in the weight of real balances, trend inflation reduces this ratio as well. This occurs since it raises the opportunity cost of holding money. More broadly, $\frac{M}{PC}$ may also be defined as the inverse consumption velocity. Assuming that consumption may equal output in steady-state in this model, the parameter κ_m may be interpreted to be the key determinant of the quantitative importance of monetary-non-neutrality in the model (Galí, 2015).

The choice of the CES MIUF and the relaxation of positive trend inflation affect the ratio of real balances with respect to consumption in the steady-state.

2.3 Deriving the linearized system

The first order condition (Eq. 7) is log-linearized around the steady-state, and conditions (Eq. 9 and Eq. 10) are imposed to yield the following money demand relationship.

$$m_t - p_t = \mu + c_t - \eta i_t \quad (12)$$

where $m_t = \ln(M_t)$, $p_t = \ln(P_t)$, $c_t = \ln(C_t)$ and $i_t = -\ln(Q_t)$.

Focusing on the parameters, $\eta = \frac{\beta}{v(\Pi - \beta)}$ may be interpreted as the semi-elasticity of money with respect to interest rates, and the constant, μ , is found to be equal to $\frac{1}{v} \left[\frac{\beta\rho}{\Pi - \beta} + \ln\left(\frac{\theta}{1 - \theta}\right) - \ln\left(\frac{\Pi - \beta}{\Pi}\right) \right]$, as demonstrated in Appendix A.1.

The key parameter η is a function of β , Π and v , while the constant term μ is a function of β , Π , v , θ , and ρ . An increase in trend inflation, Π , or the elasticity of substitution, v , would work to reduce η as well as the constant term μ . The steady-state interest rate positively affects the constant, but does not directly affect the semi-elasticity. Finally, the ratio of real balances to consumption, θ , reduces the constant term.

2.4 How does it connect with the literature?

The unit elasticity of consumption is consistent with the long-run estimate in Lucas (1988). Considering the special case of zero trend inflation by setting $\Pi = 1$

and ignoring the constant term μ delivers the money demand curve obtained in Andrés et al. (2002).

The relationship derived in Eq. 12 can also be written in the following familiar log-linear form (Lucas, 2000):

$$\ln(m_t) = \mu - \eta i_t \quad (13)$$

Eq. 13 may then be interpreted as linking the log of m_t , which represents the ratio of nominal money balances to nominal income, to the level of i_t . It is also related to the money demand function postulated by Cagan (1956):

$$\ln(m_t) = \ln(B) - \eta i_t \quad (14)$$

Setting $\ln(B) = \mu$ in Eq. 14 returns the form described in Eq. 13. Connecting this with the findings shared by Ireland (2009), who suggests this functional form to fit better the post-1980s data, suggests that it may be relevant to estimate and pin down the parameters describing Eq. 13 to better approximate the welfare cost of inflation, as well as identify the sources behind these changes.

The remaining equations are linearized to obtain the following expressions:

$$w_t - p_t = \sigma y_t + \varphi n_t + \omega i_t \quad (15)$$

$$y_t = E_t[y_{t+1}] - \frac{1}{\sigma} (i_t - E_t[\pi_{t+1}] - \rho - \omega E_t[\Delta i_{t+1}]) \quad (16)$$

where Eq. 15 and Eq. 16 are the labor supply curve and the Dynamic Investment-Saving (IS) relationship, respectively. It is further shown in Appendix A.2 that $\omega = \chi(v - \sigma)\eta$, where $\chi = \frac{(\Pi - \beta)\kappa_m}{\Pi + (\Pi - \beta)\kappa_m}$ and κ_m refers to the steady-state of the ratio of real money balances with respect to consumption. As shown in Appendix A.3, ω also enters the IS curve, making Eq. 16 sensitive to trend inflation and money.

The sign of $(v - \sigma)$ in Eq. 15 and Eq. 16 determines the sign of the effect of the nominal interest rate on labor supply. Trend inflation affects these short-run relationships through entering the term ω . Under standard calibration of the model considered in Galí (2015), high trend inflation seeks to dampen ω , thus influencing the effect of changes in the interest rate on both labor supply and consumption. Moreover, when $v > \sigma$ (implying $\omega > 0$) the reduction in real balances induced by an increase in the nominal rate lowers the marginal utility of consumption (for any given c_t), lowering the quantity of labor supplied at any given real wage. In Eq. 16 the anticipation of a nominal rate increase (and, hence, of a decline in real balances), lowers the expected one-period-ahead marginal utility of consumption (for any expected c_{t+1}), which induces an increase in current consumption (in order to smooth marginal utility over time).

Since real balances enter this equation directly, they may be relevant in determining inflation and output dynamics. As demonstrated in Appendix A.4, the effect on output can be extracted from the model using the production function (Eq. 6), the money demand curve, the labor supply curve, and the Dynamic IS:

$$y_t = \frac{1 + \varphi}{\sigma(1 - \alpha) + \varphi + \alpha} a_t - \frac{\omega(1 - \alpha)}{\sigma(1 - \alpha) + \varphi + \alpha} i_t \quad (17)$$

where under standard calibrations of α , σ and φ , the effect of interest rates to output depends on ω . Since this parameter itself is a convolution of trend inflation and the function of the weight of real balances, as well as the degree of substitutability in the utility function, changes in these parameters affect the degree of interest rate shocks on output. Hence, changes common to those that affect money demand may also influence the effect of changes in interest rates on output.

3 The Welfare Loss Function

One consequence of the changes in the money demand function identified in the empirical literature concerns the welfare cost of inflation. The classic approach developed by Bailey (1956) and Friedman (1969) treats real money balances as a consumption good and inflation as a tax on real balances. Lucas (1981) and Fischer (1981) compute such a welfare cost by calculating the area under the money demand curve, obtaining surprisingly low estimates of inflation. However, Lucas (2000), using the competing money demand specifications of Meltzer (1963), which takes on a log-log form, and Cagan (1956), which takes on a semi-log form, highlights the fact that these competing money demand specifications may have very different implications for the welfare cost of inflation. Indeed, Ireland (2009) shows that the welfare cost of inflation depends on the specification of the money-demand curve, together with finding that a semi-log form proposed by Cagan (1956), which fits better with post-1980s U.S. data, generates modest departures from Friedman's zero nominal interest rate rule.

In the first step, the functional form of the welfare cost function is captured. To do this, we apply the method of Bailey (1956), and define the welfare cost of inflation as the area under the inverse money demand function – the *consumers' surplus* – which can be gained by reducing the interest rate from some level i_t to zero and then subtracting the seigniorage revenue $i_t m_t$ to isolate the dead weight loss. Defining $m(i_t)$ as the estimated function, let $\psi(m_t)$ be the inverse function

and define the welfare cost function $w(i_t)$ by:⁵

$$w(i) = \int_{m(i)}^{m(0)} \psi(x) dx = \int_0^i m(x) dx - im(i) \quad (18)$$

The second integral shows an alternative way of calculating consumer surplus. It can be shown that under the money demand specification (Eq. 13), solving Eq. 18 implies the following welfare function:

$$w(i) = \frac{e^\mu}{\eta} \left(1 - (1 + \eta i) e^{-\eta i} \right) \quad (19)$$

It is worth highlighting the similarities between this welfare function (Eq. 19) under money demand (Eq. 13) with the welfare function used by Lucas (2000):

$$w(i) = \frac{B}{\xi} \left(1 - (1 + \xi i) e^{-\xi i} \right) \quad (20)$$

Setting $B = e^\mu$ in Eq. 19 yields the Lucas (2000) welfare function in Eq. 20. However, the micro-founded money demand and the welfare function derived in this paper explicitly link the structural parameters of the model with the welfare function by altering both the semi-elasticity and the constant term in the money demand curve.

In the second step, the money demand curve is estimated and combined with the expression similar to Eq. 19 and Eq. 20 to pin down the welfare cost of inflation. To highlight the importance of different aspects of the money demand function, we apply the well-known specification of the money demand curve (Lucas, 2000; Ireland, 2009).

The first row in Table 1 pins down welfare at different levels of inflation and nominal interest rate. The values of η and B come from Lucas (2000) based on annual data from 1900 to 1994. His preferred specifications set η , allows him to pin down an *average* value of $B = 0.3548$ so that $\ln(B)$ equals the average value of $\ln(m) + \eta i$. This, in turn, allows him to calculate the welfare cost of inflation. However, fixing η each combination of $\{\ln(m), i\}$ yields a different value of B . In this spirit, Table 1 also lists down the welfare calculations for a ‘minimum’ and ‘maximum’ value of B following Lucas’s calculations of the constant of money demand. The second panel in Table 1 repeats the same exercise, this time using the values presented in Ireland (2009), who estimates η to be equal to 1.7944 based on quarterly data from 1980 to 2006. Again, setting the elasticity at this benchmark generates both the average as well as the upper and lower bound of B .

Table 1 highlights that the differences in the welfare cost of inflation using the

⁵As all the variables are expressed in time t , we drop timing to facilitate reading in the subsequent equations.

same money demand curve may be due to two factors: the value of the semi-elasticity of money demand, and the constant of regression. Moving from a regime where high elasticity is estimated to one that is low works to reduce the welfare cost of inflation. Intuitively, a lower elasticity implies a steeper money demand curve, therefore, a lower area will represent the welfare cost. However, even with lower elasticity, if the constant of the money demand has increased then this would work to mitigate some of the fall in welfare due to money demand steepening; in this sense, the choice of B matters for the total welfare – a higher B for a given η generates a higher welfare loss. Table 1 reveals that, even if elasticity is reduced from 7 to 1.7944, it may not necessarily correspond to a fall in welfare if the constant B switches from a low value of 0.1805 to a high value of 0.4589.

			$i = 0.03$	$i = 0.05$	$i = 0.13$
	ζ	B	0% inflation	2% inflation	10% inflation
Benchmark	7	0.3548	0.0972	0.2466	1.1717
Lower Bound	7	0.1805	0.0495	0.1255	0.5962
Upper Bound	7	0.5068	0.1389	0.3524	1.6738
Benchmark	1.7944	0.2795	0.0217	0.0590	0.3633
Lower Bound	1.7944	0.1591	0.0123	0.0336	0.2068
Upper Bound	1.7944	0.4859	0.0378	0.1026	0.6316

Table 1: Welfare Estimates Note: This table outlines estimates of the welfare costs of zero, two percent, and ten percent annual inflation based on the benchmark and upper and lower bound regression results in Lucas (2000) and Ireland (2009).

In this sense, the money demand and welfare framework derived in this paper gives a unique micro-founded interpretation to the money-demand curve, and the corresponding welfare function utilized in Lucas (2000) and Ireland (2009). Viewed through the lens of this framework, the potential sources behind the differences in welfare cost obtained in Lucas (2000) and Ireland (2009) are distilled. To answer these questions, we delve into the data presented in Appendix B, which allows us to estimate the money demand curve with the intention of unraveling the differences in welfare and pinpointing the factors that may have generated these shifts in the money demand curve.

4 Estimating the Money Demand Curve

4.1 Fixed Coefficients

We estimate the money demand curve using quarterly U.S. data spanning 1959–2008. The beginning of the sample is chosen to coincide with Ireland (2004), while the end-of-sample dates are chosen to avoid dealing with the Federal Reserve’s unconventional monetary policy that began in September 2008.

Following Ireland (2009) and Miller et al. (2019), the money-income ratio is measured by dividing the Cynamon et al. (2006) sweep-adjusted M1 money stock (M1RS aggregate) by nominal GDP, the three-month U.S. Treasury bill rate, which serves as the measure of i and matches the risk-free rate, nominally-denominated bonds that serve as an alternative store of value in theoretical models of money demand.⁶

We utilize both static ordinary least squares (SOLS) and dynamic ordinary least squares (DOLS) estimates of the parameters of the money demand,⁷ linking $\ln(m)$ and i . Therefore, each of the parameter estimates in the following tables comes from an ordinary least squares (OLS) regression of $\ln(m)$ on a constant, the level of the nominal interest rate i , and leads and lags of Δi , the quarter-to-quarter change in the nominal interest rate computed using the Newey and West (1987) estimator of the regression error variance for various values of the lag truncation parameter

⁶The definition of money, and the related money aggregate's ability to estimate money demand, has been the subject of active literature (Diewert, 2013). While our preference for using the M1RS indicator to empirically document, and to assess the causes and consequences of these evolving relationships between interest rates and money, is designed to align our findings with Ireland (2009) and Lucas (2000) who rely on similar money aggregates, it is important to mention the developments in the money demand literature based on the use of Divisia money (Barnett, 1978; Barnett et al., 1984; Barnett and Chauvet, 2011). In these series of influential papers, Barnett recommends the use of a superlative index number construction of the user costs, derived from François Divisia in money aggregate construction to produce a more sophisticated measure of money that internalizes the rate of interest within its construction. In this way, the financial innovation in the economy in the form of new transactions technology or the introduction of alternative new monetary assets may be incorporated into the construction of the index number, ensuring that the money demand function remains stable even during periods of high financial innovation – see, e.g. Belongia (1996) for money demand stability, and further evidence from 11 countries by Belongia and Binner (2000). Furthermore, Belongia and Ireland (2019) argues that the identification of stable money demand functions – when estimated with Divisia quantity data and their user cost duals – is consistent with the idea that instability reported since the early 1990s may be more closely associated with measurement error than shifts in the underlying economic relationships themselves. Belongia and Ireland (2019) identify a stable money demand function over a period that includes the financial innovations of the 1980s and continues through the Global Financial Crisis (GFC) and Great Recession, suggesting that a properly-measured aggregate quantity of money can play a role in the conduct of monetary policy. More broadly, Qureshi (2016, 2018) argue that using M1 and M3, as compared to M2, may be more useful for policy purposes. Not only do their results present an alternative framework to explain the historical actions of the Fed, but the subsequent analysis suggests that the bias against the inclusion of money in mainstream macroeconomic models may be due to an overreliance on an incorrect aggregate.

⁷Roughly similar results were obtained using alternative techniques such as VECM. These results are available upon request.

q .⁸⁹

$$\ln(m) = \mu - \eta i \quad (21)$$

Focusing first on the value of η , the SOLS and the DOLS estimates are close to each other and suggest a value between 3.4542 (SOLS) and 3.8561 (DOLS with four lags and leads), confirming that the estimated interest elasticity of money demand differs significantly from zero. However, this number is estimated to be higher than that of Ireland (2009), who finds it to be in the 1.8 – 1.9 range and, at the same time, is significantly smaller in absolute value than the Lucas (2000) setting of 7. The constant of regression is estimated to be higher than that estimated in both Ireland (2009) and Lucas (2000). Table 2 summarizes these results, including estimates of welfare for various levels of inflation, calculated by plugging these numbers into the derived expression in Eq. 19.

As the static and dynamic OLS estimates look quite similar, so do the implied welfare costs.¹⁰ Assuming, as before, that the steady-state real interest rate equals three percent, so that $r = 0.03$ corresponds to zero inflation, $r = 0.05$ corresponds to two percent annual inflation, $r = 0.07$ corresponds to four percent annual inflation and $r = 0.13$ corresponds to ten percent annual inflation. Therefore, the regression coefficients put the welfare cost of pursuing a policy of price stability as opposed to the Friedman (1969) rule at less than 0.0292 percent of income, the cost of two percent inflation at less than 0.0776 percent of income, the cost of four percent inflation at less than 0.1455 percent of income, and the cost of ten percent inflation at less than 0.4389 percent of income. Interestingly, Table 2 also provides estimates of the cost of ten percent inflation compared to price stability, $w(0.13) - w(0.03)$, at approximately 0.4097 percent of income. These numbers are still larger than the Fischer (1981) estimate of 0.30 percent of income, and the Ireland (2009) estimate of 0.20 percent of income, but close to the Lucas (1981)

⁸DOLS has a number of advantages (Stock and Watson, 1993; Hamilton, 1994). First, and under the assumption of co-integration in the relationships, the DOLS estimates are asymptotically efficient and asymptotically equivalent to maximum likelihood estimates obtained, for example, through the method proposed by Johansen (1988). Second, adding leads and lags of Δi to the estimated equations controls for possible correlation between the interest rate and the residual from the co-integrating relationship, linking $\ln(m)$ and i . Finally, the conventional Wald test statistics formed from these DOLS estimates have conventional normal or chi-squared asymptotic distributions, making it possible to draw familiar comparisons between the parameter estimates and their standard errors.

⁹Since we evaluate welfare costs as a percentage of GDP, we need to formally test for the assumption of unitary income elasticity and, when evidence in its favor is found, impose it and estimate long-run money demand equations, where the natural logarithm of the money-income ratio depends on the nominal interest rate given to our micro-founded specification. Perhaps this is a restriction, but the unit elasticity of consumption is imposed by the theoretical derivation of the money demand curve – a result consistent with the long-run estimate in Lucas (1988). In any case, we directly estimate the unit elasticity and we find results consistent with those found in Ireland (2009), i.e. approximately equal to unity.

¹⁰Both statistically significant at the 1% level.

			Zero inflation	2% inflation	4% inflation	10% inflation
$m_t = \mu - \eta i_t$	μ	η	$w(0.03)$	$w(0.05)$	$w(0.07)$	$w(0.13)$
SOLS	-1.6089*** (0.0318)	3.4542*** (0.4089)	0.0292	0.0776	0.1455	0.4389
DOLS, p = 1	-1.5921*** (0.0312)	3.6188*** (0.4097)	0.0308	0.0816	0.1526	0.4576
DOLS, p = 2	-1.5868*** (0.0304)	3.7338*** (0.4105)	0.0319	0.0843	0.1575	0.4701
DOLS, p = 3	-1.5827*** (0.0299)	3.8303*** (0.4112)	0.0328	0.0866	0.1615	0.4803
DOLS, p = 4	-1.5826*** (0.0291)	3.8561*** (0.4117)	0.0330	0.0871	0.1624	0.4826

Table 2: Welfare Cost (Percent of Income). Note: This table outlines estimates of the welfare costs of zero, two percent, four percent and ten percent annual inflation based on the regression results. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

estimate of 0.45 percent of income.¹¹

Before delving into sub-sample estimates, we extract the values of trend inflation, steady-state interest and the subjective rate of time preference parameter from the data, then use the functional forms derived earlier to extract values for the two parameters in the utility function, v and θ . Table 3 summarizes the parameters obtained under the money demand estimates described in Table 2. Inflation during the sample is fixed at 3.5674 percent, which corresponds to 1.0089 in gross terms. The sample average for the interest rate is found to be 5.430 percent. These numbers permit the extraction of the elasticity (v) and the weight of real balances versus consumption in the utility function, which are 9.8968 and 0, respectively. While we find a moderate degree of inter-temporal elasticity, rejecting the restrictive CES version to represent utility, the evidence presents little evidence of real balances affecting the utility function for the entire time period of the benchmark estimates

β	Inflation (Π)	Interest (ρ)	Elasticity (v)	Weight (θ)
0.99	1.0089	0.0543	16.2189	0.0000

Table 3: Extraction of Deep Parameters Note: This table outlines the values for the parameters of the utility function based on OLS estimates from table 2 and utilizing equation (12).

Looking in detail at the elasticity of substitution, these numbers connect with Holman (1998) who find that the estimated exponent of the CES characterizations

¹¹Notice that the time period under question in the current paper is different from that considered by Ireland (2009) and Lucas (2000). In that, whereas the present study focuses on quarterly data spanning five decades from 1959, Ireland (2009) focuses only on the post-1980 period, while the bulk of the Lucas (2000) sample lies before this date.

is statistically different from zero in the nested-CES case, as well as with Galí (2015) who propose this number to be “reasonably large”. Second, given that $v \neq 1$, the results imply that utility is not separable in either consumption or money. Third, the share of real balances is in stark contrast to the findings of Holman (1998), Finn et al. (1990) and Poterba and Rotemberg (1987) who find evidence of real balances in utility. Notice that this could be due to a number of reasons, such as due to the time period under question, or the type of money aggregate used. Indeed, variation in θ may also represent shocks in transactions technology – shocks that change the utility value of money relative to that of consumption expenditures (Koenig, 1990), which are potentially time-varying. To accommodate these changes, we focus on estimating the money demand curve around key break-dates.

4.2 Split-Sample Estimates

To deal with potential instabilities, we rely on a split-sample approach to estimate the money demand function. We rely on static and dynamic OLS techniques to estimate this money demand function for the two periods: 1959:I–1979:IV and 1980:I–2008:II.¹² The break in 1980 is chosen to coincide with both the arrival of Paul Volcker at the Federal Reserve Board and the implementation of the Depository Institutions Deregulation and Monetary Control Act of 1980, which are often identified as key events marking the start of a new chapter in U.S. monetary history. As before, the end date of 2008:II is chosen to coincide with the collapse of the Lehman Brothers and the beginning of unconventional policy by the Fed.¹³ The detailed results are available in Appendix C.

Table 4 outlines the key parameters of semi-elasticity and the constant – obtained under OLS estimates. It is immediately clear from these numbers that a split-sample approach around the break-date highlights a large shift in the value of the semi-elasticity, reflecting a flattening of the money-demand curve. In this sense, our results find little disagreement with the estimate suggested by Ireland (2009). However, pre-1979 estimates paint a completely different picture because elasticity is found to be close to the estimates suggested by Lucas (2000). Furthermore, a clear and statistically significant shift in the constant term is also found as the upper and lower bounds of the estimates are tightly estimated.

Table 4 also summarizes the parameters obtained under the money demand estimates. Inflation and interest rates are pinned down from the data and vary across the sample, which is uncontroversial in the literature. These numbers permit the extraction of the elasticity (v) and the weight of real balances versus con-

¹²Note that this is because the OLS/DOLS methodology is not equipped to deal with break-dates and, thus, we simply apply the technique to two separate sub-samples.

¹³Estimates based on the crises period (2008:II–2017:IV) suggest estimates of interest-elasticity to be inconclusive as the estimates are not statistically significant. These results are available upon request.

Parameters	Pre-1979	Post-1980
η	7.5351*** (0.5332)	1.5639*** (0.0996)
μ	-1.2255*** (0.0295)	-1.8289*** (0.0061)
Inflation (Π)	1.0105	1.0076
Interest (ρ)	0.0527	0.0582
Substitution (v)	6.3539	35.8216
Weight (θ)	0.6×10^{-5}	0.2×10^{-34}

Table 4: Money Demand Estimation (Extraction of Deep Parameters) Note: This table outlines the values for the parameters of the utility function based on OLS estimates. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

sumption in the utility function. A large variation in these numbers between the two time periods is also observed. There are significant changes in the elasticity of money demand, a result which is consistent with the findings of Ireland (2009), but different from those found in Miller et al. (2019).¹⁴

First, the elasticity of substitution between consumption and real balances between the two periods is said to have fallen. Second, the share of real balances in utility implies a comparable role for money balances in the first half and a negligible role in the second. Indeed, estimates of θ in the first half present values close to those found in Holman (1998), Finn et al. (1990) and Poterba and Rotemberg (1987). Holman (1998) find liquidity services to have the largest role in the nested-CES case (ranging from 0.0242 to 0.0319); Finn et al. (1990) find that real balances comprise less than 10 percent of total expenditures; while Poterba and Rotemberg (1987) estimate that the share of expenditures on consumption is between 0.961 and 0.969. Thus, while our estimates reveal a slightly smaller role for liquidity services in the first half of the sample, the non-zero values do confirm previous findings. Moreover, since real balances enter directly the dynamic IS, they may be relevant in determining inflation and output dynamics during the first half of the sample, complementing the findings of Castelnuovo (2012).

5 Applications

5.1 Explaining Changes in the Welfare Cost of Inflation

Combining the estimates of semi-elasticity in Section 4.2 with the welfare cost function derived in Section 3, Table 5 looks at the welfare cost of inflation. Plus,

¹⁴Given that we use similar data, this difference may be due to the time-varying approach undertaken by Miller et al. (2019), which may not be consistent with the DOLS approach usually employed in the literature (Stock and Watson, 1993).

the counterfactual welfare cost is also illustrated when the constant and semi-elasticity terms in the money demand curve are varied.

Table 5 suggests that both the semi-elasticity of interest and the constant term are estimated to be higher during the pre-1979 period when compared to their post-1980 counterparts. The values for the welfare cost of inflation are not too far off from those implied in Dotsey and Ireland (1996) for the pre-1979 sample. The welfare cost of pursuing a policy of price stability as opposed to the Friedman (1969) rule at less than 0.0857 percent of income, the cost of two percent inflation at less than 0.2159 percent of income, the cost of four percent inflation at less than 0.3843 percent of income, and the cost of ten percent inflation at less than 1.0002 percent of income. Table 5 also provides estimates of the cost of ten percent inflation compared to price stability, $w(0.13) - w(0.03)$, which is approximately 0.9145 percent of income – numbers that are still larger than the Fischer (1981) estimate of 0.30 percent of income, and the Ireland (2009) estimate of 0.20 percent, and even the Lucas (1981) estimate of 0.45 percent of income. The differences with Lucas (1981) and Lucas (2000) arise primarily due to our estimate of the constant term in the money demand curve.

$m_t = \mu - \eta i_t$	μ	η	Zero inflation $w(0.03)$	2% inflation $w(0.05)$	4% inflation $w(0.07)$	10% inflation $w(0.13)$
Pre-1979						
Static OLS	-1.2255	7.5351	0.0857	0.2160	0.3844	1.0003
Switch Elasticity (η)	-1.2255	1.5640	0.0200	0.0545	0.1046	0.3392
Switch Constant (μ)	-1.8290	7.5351	0.0469	0.1181	0.2102	0.5471
Switch Inflation (Π)	-0.0803	8.8172	0.3076	0.7623	1.3355	3.3268
Switch Substitution (v)	-0.0279	1.3366	0.0570	0.1554	0.2993	0.9790
Switch Interest (ρ)	-0.1152	7.5351	0.2603	0.6556	1.1667	3.0364
Switch Weight (θ)	-4.1583	7.5351	0.0046	0.0115	0.0205	0.0533
Combined Weight & Substitution	-0.9728	1.3365	0.0221	0.0604	0.1163	0.3806
Post-1980						
Static OLS	-1.8290	1.5640	0.0110	0.0298	0.0572	0.185
Switch Elasticity (η)	-1.8290	7.5351	0.0469	0.1181	0.2102	0.5471
Switch Constant (μ)	-1.2255	1.5640	0.0200	0.0545	0.1046	0.3392
Switch Inflation (Π)	-0.7304	1.3366	0.0282	0.0770	0.1482	0.4850
Switch Substitution (v)	-4.0310	8.8172	0.0059	0.0147	0.0257	0.0640
Switch Interest (ρ)	-0.7237	1.5640	0.0331	0.0900	0.1728	0.5603
Switch Weight (θ)	0.0053	1.5640	0.0679	0.1846	0.3544	1.1493
Combined Weight & Substitution	-1.6104	8.8172	0.0666	0.1650	0.2891	0.7203

Table 5: Welfare Cost (Percent of Income): Counterfactual Experiments Note: This table outlines estimates of the welfare costs of zero, two percent, four percent and ten percent annual inflation, disaggregating these changes into two time periods, pre-1979 and post-1980. It further presents the welfare cost of inflation using counterfactual values of the underlying parameters driving the semi-elasticity and constant of the money demand curve.

A startlingly different picture emerges for the post-1980 sample, where the welfare cost of pursuing a policy of price stability as opposed to the Friedman (1969) rule reads at less than 0.0109 percent of income, the cost of two percent inflation at less than 0.0298 percent of income, the cost of four percent inflation at less than 0.0572 percent of income, and the cost of ten percent inflation at less than 0.1855 percent of income. Interestingly, Table 5 also provides estimates of the cost of ten percent inflation compared to price stability, $w(0.13) - w(0.03)$, which is approximately 0.1746 percent of income, numbers that are smaller than the Fischer (1981) estimate of 0.30 percent of income, and close to the Ireland (2009) estimate of 0.20 percent. Broadly, Table 5 points to large changes in welfare across the two time periods.

Looking at counterfactual evidence, it is clear from Table 5 that not only switching the elasticity term but also the switch in the constant term has large implications on the welfare cost of inflation. Focusing first on the pre-1979 time-period,

switching the elasticity parameter contributes to an almost 50% fall in welfare, while switching the constant terms generates a fall of approximately 30%. In contrast, opposing results emerge for the post-1980 period.

The underlying factors of the shifts in the money demand curve reveal the true sources of the changes in the welfare cost of inflation. The first block in Table 5 pinpoints the welfare cost of inflation in the pre-1979 sample, setting each of the underlying sources at post-1980 values. First, lower inflation works to increase both the elasticity and the constant parameter, increasing the welfare cost of inflation. Second, a shift in the elasticity of substitution generates a rise in the constant term but a fall in the semi-elasticity of interest term. A switch in steady-state interest rates generates a larger constant term and, therefore, a larger loss in welfare. Considering the share of real balances extracted in the post-1980s sample to calculate the constant term for the pre-1979 sample, we find that this generates a large fall in welfare despite being roughly the same elasticity of interest rates. Our calculations suggest that the combined effect of a reduction in the weight of real balances and the elasticity of substitution between real balances and consumption work to reduce the welfare cost in the first sample.

Moving onto the second half of the sample reveals similar insights. Replacing a higher value of trend inflation or a lower value of the steady-state interest rate works to reduce the semi-elasticity but increases the constant term, generating a larger fall in inflation. The elasticity of substitution generates a larger η but a lower value of the constant. Finally, considering the share of real balances extracted in the pre-1979 sample to calculate the constant term for the post-1980 sample generates a large rise in welfare, this roughly matching the welfare costs observed in the first half of the sample.

What might justify these results? First, the evidence in favor of the time dependence of the deep parameters may be interpreted as time-varying preferences by American households, or as evidence in favor of breaks due to financial innovation, as argued by Castelnovo (2012). Indeed, Justiniano and Primiceri (2008) enumerate important elements of this transformation, such as the passing of the Depository Institutions Deregulation and Monetary Control Act in 1980 – particularly the demise of regulation Q, and the Garn-St. Germain Depository Institutions Act of 1982 (Hendershott, 1992; Dynan et al., 2006; Campbell and Hercowitz, 2009). These changes allowed households unprecedented access to external financing (Campbell and Hercowitz, 2009), which was further facilitated by the emergence of secondary mortgage markets (Peek and Wilcox, 2006; McCarthy and Peach, 2002). Moreover, access to external financing was enhanced by the development of a market for bonds with below-investment grade ratings (Gertler and Lown, 1999), as well as a decline in the cost of new equity issuances (Jermann and Quadrini, 2006).

The irrelevance of more traditional money aggregates and the emergence of complementary sources of finance for households may imply a weakening of the semi-elasticity of interest. This has perhaps worked to reduce the welfare cost of inflation. Looking at this argument another way, money holdings yield direct utility in the model in a standard framework. Since the importance of real balances seems to decline in the second half of the sample, so does their contribution to welfare.

5.2 Recursive Estimates

It has been documented by several authors that post-WWII U.S. macroeconomic relationships may be characterized by instabilities that might not even be captured using a single split-sample approach. The time-varying aspect of the semi-elasticity has also been discussed in the literature.¹⁵ The evolution of financial services, in particular, may be characterized by a gradual change in the behavior of households. Accounting for the possibly evolving role played by the underlying factors is, therefore, of crucial importance for achieving correct identification of the underlying drivers of the changes in money demand.

Following Castelnuovo (2012), we tackle this issue by recursively estimating the money demand curve with OLS techniques. We estimate the evolution of the parameters constructed by employing seven rolling windows of 16-year constant length. We then extract the underlying structural parameters based on time-varying estimates of semi-elasticity of interest, which are pictured in Fig. 1.

It is apparent from Fig. 1 that changes in the semi-elasticity and the constant term in the money demand function occurred gradually, starting well before the 1980s. These terms are seen declining as the sample moves through observations conditioned to the 1970s – a period accompanied by rising interest rates and inflation – and a gradually-rising elasticity of substitution between consumption and real balances.

Fig. 1 suggests two large shifts in the semi-elasticity of interest rates, instead of occurring around the commonly considered split-sample break. The decline in semi-elasticity occurs when moving from the window dated 1963:I–1978:IV to the 1967:I–1982:IV. The semi-elasticity of interest is observed to decline substantially from around 5.8715 to 3.9536 during this period. However, the underlying utility parameters display remarkable stability during this period. Looking closely, this change in semi-elasticity is attributed to the rise in trend inflation from 4.7994 to 6.194 percent. A smaller change in the constant is observed that, given the stability of the underlying utility parameters, is attributed to the rise in interest rates.

¹⁵See, for instance, Khan (1974), Judd and Scadding (1982), Tesfatsion and Veitch (1990), Hafer and Jansen (1991), Miller (1991), Lütkepohl (1993), Ireland (2009), Lucas and Nicolini (2015), and Miller et al. (2019).

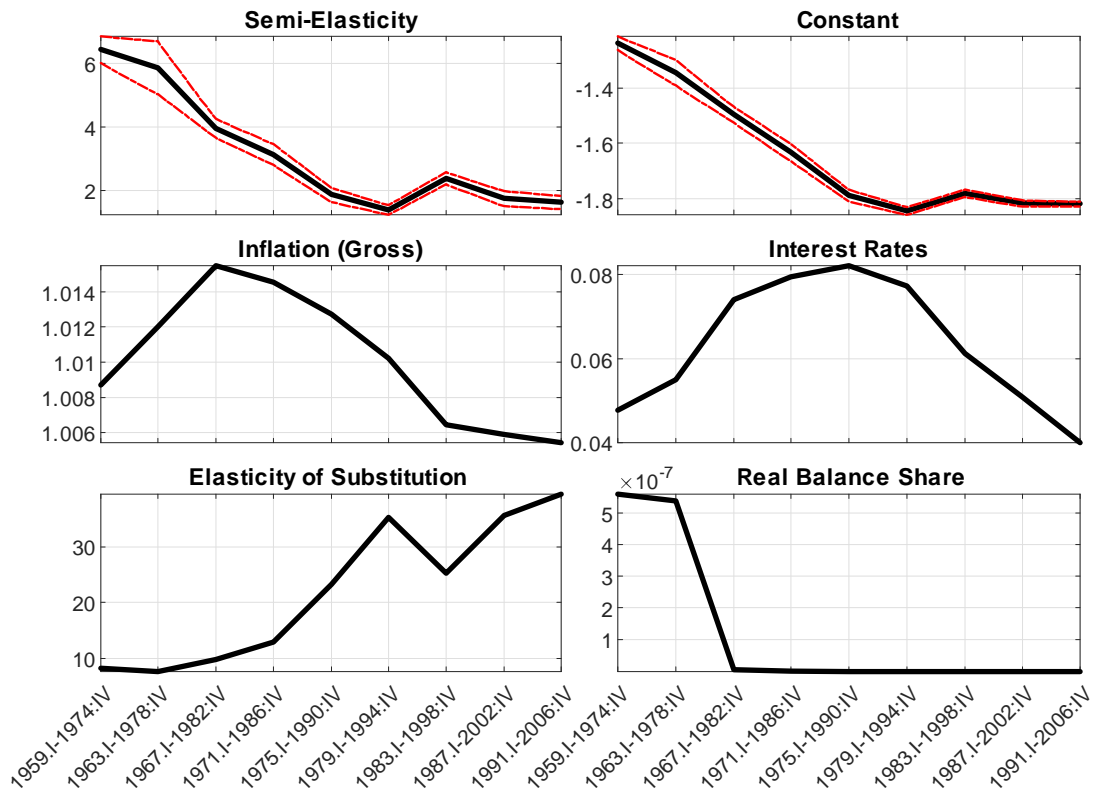


Figure 1: Time-varying Money-Demand Parameters. Note: This figure presents estimates of the semi-elasticity of interest rate and the constant in the money demand curve as well as the underlying parameters and first moments from actual data. Evolution of the parameters constructed by employing seven rolling windows of 16-year constant length. The dotted lines plot the standard errors of the 5 and 95 percent confidence intervals.

The second sharp fall in the semi-elasticity of interest rates is observed when moving from the window 1971:I–1986:IV to 1975:I–1990:IV. The semi-elasticity of interest declines substantially from around 3.1337 to 1.8716 during this period. However, in this case, both inflation and interest rates, while not constant, display remarkable stability. From the data, inflation is averaged at around 5 percent, while interest rates rise only marginally from 7.9401 to 8.2085. In this case, a sharper change is observed in the elasticity of substitution between consumption and real balances, which almost doubles from 12.8699 to 23.2613. The share in real balances in the utility function declines to zero.

On closer inspection, movements in semi-elasticity of interest toward the latter half of the sample could be attributed to changes in the elasticity of substitution between consumption and real balances. While the elasticity of substitution works to reduce the semi-elasticity of interest rates, the decline in the share of real balances in utility is the key factor behind the decline in the constant term. One possible explanation for this factor may lie in financial innovation increases during this period. The availability of alternative sources of payments may cause the share of real balances in utility to fall, as households have a lower reliance on this particular aggregate. Because households now hold fewer real balances, the degree of substitutability for those lower levels of real balances falls. With households now holding a lesser share, they are less inclined to substitute those real balances. For the limited amount of real balances held that are more valuable than before, the opportunity cost rises, which affects the welfare cost of inflation.

Table 6 outlines the results from the rolling window estimates, tabulating the values of inflation, interest rates, semi-elasticity, and the share of real balances, as well as the welfare cost of inflation observed.

Sample	η μ		ρ π v θ				Zero	2%	4%	10%
							Inflation w (0.03)	Inflation w (0.05)	Inflation w (0.07)	Inflation w (0.13)
1959.I–1974:IV	6.4441	−1.2366	0.0476	1.0087	8.2059	0.5×10^{-6}	0.0741	0.1892	0.3413	0.9230
1963.I–1978:IV	5.8715	−1.3432	0.0551	1.0120	7.6646	0.5×10^{-6}	0.0614	0.1579	0.2868	0.7916
1967.I–1982:IV	3.9537	−1.4967	0.0740	1.0155	9.8254	0.5×10^{-8}	0.0368	0.0971	0.1807	0.5349
1971.I–1986:IV	3.1338	−1.6332	0.0794	1.0145	12.8699	0.2×10^{-10}	0.0259	0.0690	0.1297	0.3960
1975.I–1990:IV	1.8717	−1.7888	0.0821	1.0127	23.2613	0.5×10^{-22}	0.0136	0.0368	0.0703	0.2252
1979.I–1994:IV	1.3891	−1.8450	0.0773	1.0102	35.2411	0.3×10^{-24}	0.0096	0.0262	0.0504	0.1646
1983.I–1998:IV	2.3885	−1.7813	0.0612	1.0064	25.2198	0.1×10^{-22}	0.0173	0.0465	0.0882	0.2771
1987.I–2002:IV	1.7525	−1.8174	0.0509	1.0059	35.5866	0.6×10^{-32}	0.0124	0.0336	0.0643	0.2070
1991.I–2006:IV	1.6289	−1.8191	0.0399	1.0054	39.4494	0.9×10^{-35}	0.0115	0.0313	0.0600	0.1941

Table 6: Rolling Window Estimates Note: This table outlines estimates of the semi-elasticity of interest rate, the constant in the money demand curve, the underlying parameters and first moments from actual data and the welfare cost of inflation. Evolution of the parameters constructed by employing seven rolling windows of 16-year constant length. Windows: [1959:I – 1974:IV, 1963:I – 1978:IV, ..., 1990:I – 2006:IV].

Assuming, as before, that the steady-state real interest rate equals three percent so that $r = 0.03$ corresponds to zero inflation, $r = 0.05$ corresponds to two percent annual inflation, $r = 0.07$ corresponds to four percent annual inflation and $r = 0.13$ corresponds to ten percent annual inflation, this means that Table 6 confirms the gradual fall in welfare cost of inflation at different levels of interest rates and inflation. Indeed, the welfare cost is found to be declining gradually. Corresponding to the decline is the semi-elasticity of interest rates, which occurs moderately due to the constant, while the second decline is due to a combined change in semi-elasticity of interest and the constant term. According to our results, the first change is primarily attributed to a rise in trend inflation and interest rates, while the second shift is attributed to changes in the utility function – in particular to the changes in the elasticity of substitution between consumption and real balances, and to the fall of the share of real balances by households.

Table 6 also provides estimates of the cost of ten percent inflation compared to price stability, $w(0.13) - w(0.03)$ at various junctures in time, starting from approximately 0.9230 in the first window and declining to almost 0.1941. The numbers obtained for each data sample encompass the conflicting findings in the previous literature. At the same time, these results indicate that the single-valued approach to approximate the welfare cost of inflation in previous literature captures only the sample average at each point in time.

When combined, our results suggest that the entire shift in money demand could be attributed to the evolution of trend inflation, interest rates, and changes in the utility function. This offers an alternative explanation for the changes observed in the traditional money demand relationship.

5.3 Assessing Changes in the Monetary Transmission Mechanism

As documented earlier, several authors have presented evidence of large changes that took place in the U.S. economy during the 1980s. For example, Boivin and Giannoni (2002) test whether the monetary transmission mechanism has changed. They examine whether the macroeconomic effects of monetary policy shocks in the U.S. were different in the 1980s and 1990s relative to the 1960s and 1970s. They conclude that changes in the monetary policy rule are responsible for the change in the impulse response of inflation and output. Pancrazi and Vukotic (2019) test whether conventional monetary policy instruments maintained the same effectiveness to accommodate any undesirable effects of shocks throughout the post-war period. They too find that the effectiveness of monetary policy (its ability to counteract undesired shocks) has declined, though they identify the changed properties of the labor market as proving the key contribution to this decline.

Theoretical results suggest that changes common to those that affect money demand may also influence the effect of changes in interest rates on output (Sec-

tion 2). Intuitively, since real balances, the elasticity of substitution between consumption and real balances in the utility function, and trend inflation enter the IS equation, changes in these parameters may affect the linkages between interest rates on output.

To test these changes from the data, we begin by documenting evidence regarding changes in the monetary transmission mechanism for the U.S., replicating, in essence, the findings of Boivin and Giannoni (2002). The baseline empirical model of the economy is a VAR in variables describing the economy (Z_t) as well as monetary policy (R_t):

$$\begin{bmatrix} Z_t \\ R_t \end{bmatrix} = \alpha + A(L) \begin{bmatrix} Z_{t-1} \\ R_{t-1} \end{bmatrix} + \epsilon_t \quad (22)$$

The structural block is described by the vector $Z_t = [y_t, \pi_t]'$, of output gap (y_t) and the annualized inflation rate (π_t). The policy instrument R_t is assumed to be the 3-month treasuring bill used earlier.¹⁶

To be consistent with recent VAR analyses, we assume that the economy (Z_t) responds only with a lag to changes in the policy instrument (R_t). The recursive VAR follows closely the notation used in Boivin (2006) and is expressed as:

$$Z_t = \Phi_0 + \sum_{i=1}^p \Phi_{1,i}^Z Z_{t-i} + \sum_{i=1}^p \Phi_{1,i}^R R_{t-i} + \epsilon_t^Z \quad (23)$$

$$R_t = \Phi_1 + \sum_{i=1}^p \Phi_{2,i}^Z Z_{t-i} + \sum_{i=1}^p \Phi_{2,i}^R R_{t-i} + \epsilon_t^R \quad (24)$$

In particular, we assess the changes in the effects of monetary policy by comparing impulse response functions of the output gap, inflation, and the Fed funds rate to a monetary policy shock using the VAR estimated over two different subsamples.¹⁷

¹⁶Several clarifications are in order. First, we do not include a commodity price measure since it is not formally justified by the theoretical model, but is only included to limit the extent of the price puzzle in this VAR, as discussed in Boivin (2006). Moreover, Christiano et al. (1996) show that, while including different indices of price commodity limits the price puzzle, it is not justified theoretically. Second, in each series, our results remain robust for including the output gap instead of output growth.

¹⁷Based on evidence listed earlier regarding the conduct of monetary policy, we base our results on the following subsamples: sample 1 corresponding to 1959:I–1979:IV and sample 2 corresponding to 1980:I–2008:II. While Boivin (2006) find slightly different results when they use 1984 as the break-point, Stock and Watson (2003) show that this break date is very imprecisely estimated. They find confidence intervals for the break date that essentially encompass all of the 1980s, hence justifying our choice for the break-date.

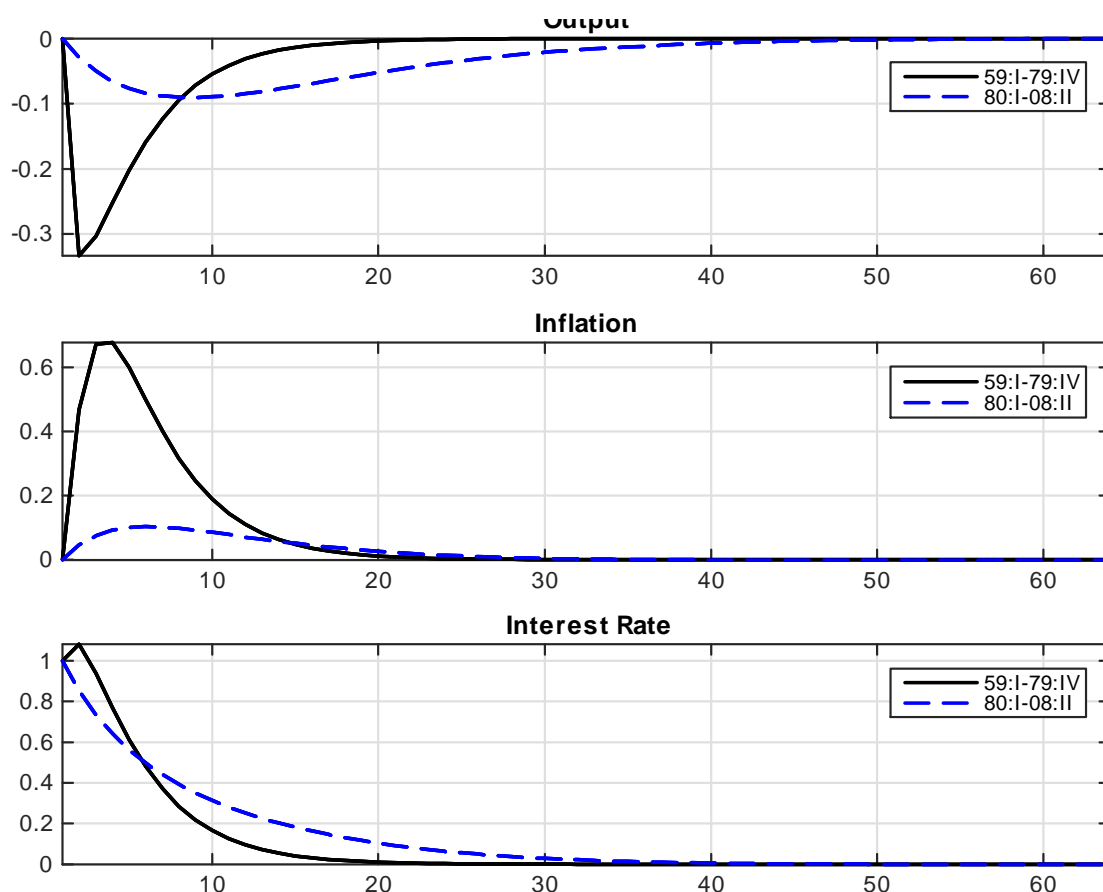


Figure 2: VAR Evidence: Impact of Unit Shock to Interest Rates on Output and Inflation. Note: This figure presents impulse responses to a monetary shock over the two sub-samples, 1959:I – 1979:IV and 1980:I – 2008:II. The solid line plots the impulse response for the 1959:I – 1979:IV sample while the dashed line plots the impulse response for the 1980:I – 2008:II time period.

Fig. 2 displays the impulse response functions for an unexpected unit increase in the 3-month T-bill rate from the identified VAR, summarizing the specific changes in the transmission mechanism discussed in Boivin and Giannoni (2002) and Pancrazi and Vukotic (2019). It is clear that a unit change in interest rates seems to have had a dissimilar initial impact on inflation and output gap, and is conditional on the type of time period analyzed.

Similar to Boivin and Giannoni (2002), we also confirm these changes by comparing the differences in the means of the response to interest rates. Both output and inflation display statistically significant differences; the p-values of output and inflation – of 0.0000 and 0.0166, respectively – confirm the statistically significant changes in the transmission mechanism, despite roughly the same impact on interest rates (p-value of 0.8817) across the two time-periods.

To quantify these changes, we construct a measure of the impact elasticity, de-

noted by ϵ_{MP} as:

$$\epsilon_{MP,t} = \frac{\sum_{i=1}^j \tilde{y}_{t+i}}{\sum_{i=1}^j \tilde{r}_{t+i}} \quad (25)$$

where the variables \tilde{y} and \tilde{r} are the impulse response of a one-unit policy innovation and j is the horizon of the period analyzed. Thus, the combined effect of a unit change in interest rates on output is the sum of the effect of output divided by interest rates at each point in time. Taking the average of this number yields a measure of the impact elasticity of monetary policy on output. The measure of elasticity is similar to that constructed by Pancrazi and Vukotic (2019). The change in $\epsilon_{MP,t}$ conditioned on the two periods is measured as:

$$\epsilon_{MP} = \frac{\epsilon_{MP,pre-1979}}{\epsilon_{MP,post-1980}} \quad (26)$$

Table 7 summarizes the impact elasticity for different time-horizons. For the benchmark case, where the horizon – represented here in quarters – is relatively shorter, the value of ϵ_{MP} is equal to 1.22. This implies that the effect on output for the unit monetary policy shock has declined by almost 18% in the second half of the sample.¹⁸ Values vary for the horizon considered. For the 12-period sample, as an example, this value rises to approximately 1.70, or a 42% reduction in the effect on output for the unit monetary policy shock. Although lower over the medium-term, the impact elasticity remains the same. These changes are larger for the short-run, and seem to decline over the medium-to-long-run; a result that seems to converge with the findings of Pancrazi (2014) who finds little evidence of these changes in the medium-term.

We present an alternative explanation for the decline in impact-elasticity. We argue that the fall in the share of real balances and a decrease in elasticity of substitution between consumption and real balances affect the key parameters that determine the degree of monetary neutrality, as shown in the theoretical model. Due to financial innovation, or the availability of alternative sources of payments, the share of real balances in utility falls as households have a lower reliance on this particular aggregate. Because households now hold fewer real balances, the degree of substitutability for those lower levels of real balances falls. For the lesser share of real balances households now hold, they become less inclined to substitute them. Since these variables enter the IS equation, changes in these parameters may affect linkages between interest rates on output.

We calculate the effect on output to changes in interest rate using the theoretical model. This can be summarized from the Dynamic IS relationship presented in Eq. 16.

¹⁸See $j = 48$ in Table 7.

Horizon (j)	Impact Elasticity		Percentage	
	Pre-1979	Post-1980	Reduction	
$j = 4$	0.2350	0.0449	5.2337	80.8932
$j = 8$	0.2654	0.0945	2.8083	64.3919
$j = 12$	0.2720	0.1323	2.0559	51.3606
$j = 16$	0.2740	0.1603	1.7089	41.4838
$j = 20$	0.2746	0.1807	1.5194	34.1865
$j = 24$	0.2747	0.1953	1.4067	28.9104
$j = 28$	0.2748	0.2056	1.3364	25.1717
$j = 32$	0.2748	0.2128	1.2916	22.5754
$j = 36$	0.2748	0.2176	1.2629	20.8190
$j = 40$	0.2748	0.2208	1.2446	19.6551
$j = 44$	0.2748	0.2229	1.2332	18.9097
$j = 48$	0.2748	0.2241	1.2262	18.4467
$j = 52$	0.2748	0.2249	1.2221	18.1708
$j = 56$	0.2748	0.2253	1.2197	18.0095
$j = 60$	0.2748	0.2256	1.2184	17.9232
$j = 64$	0.2748	0.2257	1.2177	17.8803

Table 7: Impact Elasticity Note: This table outlines the impact elasticity of monetary policy based on equation (25), and by comparing the period before and after the 1980s.

	κ_m	η	χ	ω	ψ
Pre-1979					
Benchmark	0.279	7.5351	0.0056	0.229	0.0763
Switch Inflation (Π)	0.2858	8.8172	0.0049	0.2354	0.0784
Switch Weight (θ)	0.3×10^{-4}	7.5351	0.6×10^{-6}	0.3×10^{-4}	0.8×10^{-5}
Switch Substitution (v)	0.7973	1.3365	0.016	0.747	0.249
Combined Weight & Substitution	-0.1555	1.3365	0.0031	0.1476	0.0492
Post-1980					
Benchmark	0.1562	1.5639	0.0027	0.1488	0.0496
Switch Inflation (Π)	0.1555	1.3365	0.0031	0.1476	0.0492
Switch Weight (θ)	0.8008	1.5639	0.0138	0.7542	0.2514
Switch Substitution (v)	0.3×10^{-4}	8.8172	0.5×10^{-6}	0.2×10^{-4}	0.8×10^{-5}
Combined Weight & Substitution	0.2858	8.8172	0.0049	0.2354	0.0784

Table 8: Measure of Monetary Neutrality: Counterfactual Experiments Note: This table outlines the key parameters of the model which underlie monetary neutralities.

Table 8 presents values of κ_m , χ , η , and the value of $\psi = \frac{\omega(1-\alpha)}{\sigma(1-\alpha)+\varphi+\alpha}$, which measures the degree of monetary neutrality implied by the model. It is immediately clear, comparing the values of $\psi_{pre-1979}$ and $\psi_{post-1980}$, that the transmission mechanism has changed. Indeed, $\epsilon_{MP} = \frac{\epsilon_{MP,pre-1979}}{\epsilon_{MP,post-1980}}$, is estimated to be around 1.58, lying within the intervals for the VAR at different horizons, and roughly matching the average impact-elasticity of monetary policy found earlier (1.7004).

The framework suggests that the changes in the utility function, perhaps due to financial innovation, may not only explain changes in the money demand relationships and the welfare cost of inflation but also a large part of the decline in monetary policy effectiveness.¹⁹

6 Conclusion

This paper empirically documents and assesses the causes and consequences of the evolving relationship between interest rates and money. Using a CES MIUF specification, we show that the interest semi-elasticity of money demand is a function of the household's preferences to hold real balances and substitute consumption and real balances, and trend inflation. Our results give rise to a general micro-founded expression for the welfare cost of inflation. Our time-varying estimates based on quarterly U.S. data revealed that there was a gradual fall in the interest semi-elasticity of money demand and the welfare cost of inflation during the period spanning 1959 to 2006. The interest elasticity of money demand fell by approximately one-third during the 1970s due to high trend inflation, and further fell during the 1980s due to the changing household preferences that emerged in response to financial innovation. These developments substantially reduced the welfare cost of inflation. We further showed that the changes in the household's preferences explained a large part of the decline in the monetary policy effectiveness that was observed in the post-1980 era.

This paper adds to the findings of previous studies in several ways. Our micro-founded interpretation of the interest semi-elasticity of money demand and the welfare cost of inflation generates clear insights into the structural factors that underpinned the changes observed in the periods of interest. Finally, the results indicate that households do not separate their preferences with regards to consumption and real money, and that trend inflation, the preference for the present (discount factor), and this nonseparability preference play a similar role. The more trend inflation or the nonseparability coefficient increases, or the more the dis-

¹⁹While there may be other changes that may explain changes in monetary policy, such as financial dislocations, the saving glut, financial globalization and the "dilemma", among many others, the paper adds to this list by presenting another explanation for the decline in monetary policy potency.

count factor decreases, the more monetary neutrality increases. Consequently, as money supply equals its demand at each point of time, monetary neutrality influences two distinct central bank tools: interest rate decisions and money supply. Monetary neutrality requires high durable inflation, decreased preference for the present, and an increased household's preference to substitute money holdings and consumption. To manage monetary neutrality, the central bank has to decrease trend inflation to reach its inflation target in the long run—and being credible—and to change household's preferences to prefer the present and substitute less between consumption and money holdings.

This policy recommendation is twofold. First, the central bank has to concretely act against high trend inflation through conventional or unconventional monetary policy decisions. Second, the central bank has to influence household preferences through communication. Doing so, the central bank will manage monetary neutrality in order to avoid instability, increase its credibility, and reinforce its tools.

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Appendix

A Derivations

A.1 Money demand

Taking Eq. 7 in logs yield

$$m_t = -\frac{1}{v} \ln(1 - \exp(-i_t)) + \frac{1}{v} \ln\left(\frac{\theta}{1 - \theta}\right) \quad (27)$$

By expanding the first term on the LHS we obtain:

$$m_t = -\frac{1}{v} \ln(1 - Q) + \frac{Q}{\ln(1 - Q)} (i_t - \rho) + \frac{1}{v} \ln\left(\frac{\theta}{1 - \theta}\right) \quad (28)$$

where $\exp(-i) = Q$ is the steady-state bond price at maturity.

Imposing the steady-state relationship, $Q = \Pi\beta$, leads to:

$$m_t = -\frac{\beta}{v(\Pi - \beta)} i_t + \frac{1}{v} \left[\frac{\beta\rho}{v(\Pi - \beta)} - \ln\left(\frac{\Pi - \beta}{\Pi}\right) + \ln\left(\frac{\theta}{1 - \theta}\right) \right] \quad (29)$$

which is the expression found in Section 2.3.

A.2 Labor Supply

We proceed with deriving the labor schedule in log-deviations from steady-state:

$$w_t - p_t = \sigma c_t + \varphi n_t + (v - \sigma)(c_t - x_t) \quad (30)$$

To eliminate x_t , we first derive it using the composite consumption-real money balances index:

$$X_t = \left[(1 - \theta) C_t^{1-v} + \theta \left(\frac{M_t}{P_t} \right)^{1-v} \right]^{\frac{1}{1-v}} \quad (31)$$

A first-order Taylor approximation of X_t around the steady-state leads to:

$$x_t = \frac{(1 - \theta) C^{1-v}}{(1 - \theta) C^{1-v} + \theta \left(\frac{M_t}{P_t} \right)^{1-v}} c_t + \frac{\theta \left(\frac{M_t}{P_t} \right)^{1-v}}{(1 - \theta) C^{1-v} + \theta \left(\frac{M_t}{P_t} \right)^{1-v}} (m_t - p_t) \quad (32)$$

Plugging this into the labor supply schedule:

$$w_t - p_t = \sigma c_t + \varphi n_t + (v - \sigma) \left(c_t - \frac{(1-\theta)C^{1-v}}{(1-\theta)C^{1-v} + \theta \left(\frac{M_t}{P_t}\right)^{1-v}} c_t + \frac{\theta \left(\frac{M_t}{P_t}\right)^{1-v}}{(1-\theta)C^{1-v} + \theta \left(\frac{M_t}{P_t}\right)^{1-v}} (m_t - p_t) \right) \quad (33)$$

which can be simplified to obtain:

$$w_t - p_t = \sigma c_t + \varphi n_t + \chi (v - \sigma) (c_t - (m_t - p_t)) \quad (34)$$

where $\chi = \frac{\theta \left(\frac{M_t}{P_t}\right)^{1-v}}{(1-\theta)C^{1-v} + \theta \left(\frac{M_t}{P_t}\right)^{1-v}} = \frac{\theta \kappa_m^{1-v}}{1-\theta + \theta \kappa_m^{1-v}}$ and hence:

$$\chi = \frac{\kappa_m}{\frac{1-\theta}{\theta} \kappa_m^v + \kappa_m} \quad (35)$$

Eq. 11 shows:

$$\frac{M}{PC} = \left(\frac{\Pi \theta}{(\Pi - \beta)(1 - \theta)} \right)^{\frac{1}{v}} = \kappa_m \quad (36)$$

Combining Eq. 35 and Eq. 36, we obtain the following expression:

$$\chi = \frac{(\Pi - \beta) \kappa_m}{\Pi + (\Pi - \beta) \kappa_m} \quad (37)$$

Finally, using the money-demand curve, we obtain:

$$w_t - p_t = \sigma c_t + \varphi n_t + \omega i_t \quad (38)$$

where $\omega = \chi (v - \sigma) \eta$.

A.3 Dynamic IS

The Euler equation is log-linearized to obtain:

$$c_t = E_t [c_{t+1}] - \frac{1}{\sigma} (i_t - E_t [\pi_{t+1}] - \rho - (v - \sigma) E_t [c_{t+1}] - x_{t+1} - (c_t - x_t)) \quad (39)$$

Again, eliminating x_t we get the following expression:

$$c_t = E_t [c_{t+1}] - \frac{1}{\sigma} (i_t - E_t [\pi_{t+1}] - \rho - \chi (v - \sigma) E_t c_{t+1} - c_t - [(m_{t+1} - p_{t+1}) - (m_t - p_t)]) \quad (40)$$

As before, $c_{t+1} - c_t - [(m_{t+1} - p_{t+1}) - (m_t - p_t)]$ is eliminated using the money demand function and imposing the market clearing condition $y_t = c_t$:

$$y_t = E_t [y_{t+1}] - \frac{1}{\sigma} (i_t - E_t \pi_{t+1} - \rho - \omega E_t [\Delta i_{t+1}]) \quad (41)$$

A.4 Effects of Policy Shocks

To obtain Eq. 17, the production function is log linearized to obtain:

$$n_t = \frac{1}{1 - \alpha} (y_t - a_t) \quad (42)$$

Labor market equilibrium is needed to obtain Eq. 17. Log-linearizing the labor demand equation:

$$a_t - \alpha n_t = w_t - p_t \quad (43)$$

which, in combination with the labor supply schedule, gives rise to the following equilibrium condition:

$$\sigma y_t + \varphi n_t + \omega i_t = a_t - \alpha n_t \quad (44)$$

Plugging in the Eq. 42 to substitute out n_t yields the Eq. 17 where $\psi = \frac{\omega(1-\alpha)}{\sigma(1-\alpha)+\varphi+\alpha}$ captures the elasticity of output with respect to interest rates.

ψ is a function of trend inflation, the elasticity of substitution and the share of real balances since these terms enter the convolution in ω .

B Data summary

Table 9 presents the data used in our empirical exercises.

Variable	Data	Time-period	Source
Interest Rates	U.S. Three month Treasury bill rate	1959:I – 2008:II	FRED
Money-income ratio	Divide the Cynamon et al. (2006) sweep adjusted M1 money stock the M1RS aggregate, by nominal GDP	1959:I – 2008:II	FRED

Table 9: Data summary Note: FRED stands for the Federal Reserve Economic Data, Federal Reserve Bank of St. Louis.

C DOLS Estimates of the Split-Sample Estimation

Table 10 presents DOLS and OLS estimates of the split-sample money demand equation estimation considered in Section 4.2.

	Pre-1979		Post-1980	
$m_t = \mu - \eta i_t$	μ	η	μ	η
SOLS	-1.2255	7.5351	-1.8920	1.5640
DOLS, p = 1	-1.1971	8.1235	-1.8226	1.6317
DOLS, p = 2	-1.1721	8.6419	-1.8201	1.6562
DOLS, p = 3	-1.1232	9.6221	-1.8215	-1.6018
DOLS, p = 4	-1.0854	10.335	-1.8234	-1.5337

Table 10: Robustness of Split-Sample Estimate. Note: This table outlines estimates of the money demand curve using both SOLS and DOLS estimates.