Monetary Policy and the Transaction Role of Money in the United States*

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January 6, 2014

Abstract

The declining importance of money in transactions can explain the well-known fact that U.S. interest rate policy was passive in the pre-Volcker period and active after 1982. We generalize a standard cashless New Keynesian model (Woodford, 2003) by incorporating an explicit transaction role for money. In the pre-Volcker period, we estimate that money did play an important role and determinacy required a passive interest rate policy. However, after 1982, money no longer played an important role in facilitating transactions. Correspondingly, the conventional view prevails and an active policy ensured equilibrium determinacy.

JEL classification: C11, C52, E52, E32
Keywords: Monetary Policy, Transaction Role of Money, Indeterminacy, Taylor Rules

* We are especially thankful to Klaus Adam, Andrew Blake, Larry Christiano, Fiorella De Fiore, Wouter den Haan, Marty Eichenbaum, Ester Faia, Andreas Schabert, and Annette Vissing-Jorgensen. Moreover, we want to thank seminar participants at the University of Amsterdam, University of Mannheim, University of Bonn, the University of Alicante, Bank of England, the Canadian Economic Association in Quebec, the Annual Congress of the European Economic Association in Glasgow, and the Royal Economic Society Annual Conference at Royal Holloway. The paper previously circulated as "Money and Reality".

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1 Introduction

Clarida, Galí, and Gertler (2000) and Lubik and Schorfheide (2004) documented a change in the conduct of interest rate policy in the United States for the time periods before Paul Volcker became chairman of the Federal Reserve in 1979 and after the disinflation years (1979–1982). They found that interest rate policy was passive before the Volcker era and active after the disinflation years.[1] The passive interest rate policy before Volcker is difficult to interpret through the lens of a standard cashless New Keynesian model (Woodford, 2003), because it must lead to indeterminacy. Consequently, by pursuing a passive interest rate policy, the Fed thus induced the possibility of sunspot fluctuations as a source of macroeconomic instability. In this paper, we provide an alternative explanation for the switch in interest rate policy. In our explanation, the Fed did not destabilize the economy before Volcker. Instead, we argue that the decreasing role of money in transactions can rationalize the switch in the interest rate policy from a passive to an active setting in the United States.

To make this argument, we generalize the standard cashless New Keynesian model by incorporating an explicit transaction role of money. This modeling choice is motivated by studies that documented decreases in the use of money in transactions (Castelnuovo, 2012; Humphrey, 2004; Schreft and Smith, 2000) and its vanishing predictive power for income (Friedman and Kuttner, 1992). In our model, a passive interest rate policy ensures determinacy if money plays an important role in transactions. In line with conventional wisdom, if money is not important in facilitating transactions an active interest rate setting leads to determinacy and a passive interest rate policy to indeterminacy. We estimate the model twice – using U.S. data before Volcker and data after 1982. Our main result is that interest rate policy before Volcker was passive but still ensured determinacy because money played an important role in facilitating transactions. Consistent with Clarida, Galí, and Gertler (2000) and Lubik and Schorfheide (2004), an active interest rate policy ensured determinacy in the United States after 1982 when money no longer played an important role.

In our model, an increase in beginning-of-period money balances reduces the real resource costs of transaction (Sims, 1994; Schmitt-Grohé and Uribe, 2004; Feenstra, 1986; Svensson, 1985). The size of the transaction friction depends on the the marginal cost-saving effect of

[1] According to the Taylor principle (activeness), monetary policy should aggressively fight inflation by raising the nominal interest rate by more than the increase in inflation above target, increasing the real interest rate. A passive interest rate policy also increases the nominal interest rates but results in a decrease of the real interest rate after an increase in inflation.

holding money balances. If the marginal cost-saving effect is zero, our model reduces to a standard cashless economy in the sense that the evolution of inflation and output can be analyzed separately from real money balances. If the marginal cost-saving effect of holding money balances is positive, equilibrium sequences are characterized by non-separability of real money balances and consumption, and predetermined real money balances serve as an endogenous state variable. Changes in the real interest rate now not only affect the consumption-savings decision but also influence the accumulation of households' real money holdings. In our theoretical analysis, we provide a complete analytical characterization of locally stable but not necessarily determinate equilibrium sequences. We show that if the size of the transaction friction exceeds a lower bound, interest rate policy must be passive to ensure determinacy. An active interest rate policy according to the Taylor principle leads to explosive equilibrium sequences.

To see why the Taylor principle can induce explosive equilibrium sequences, suppose that an adverse technology shock occurs. As a reaction to the increase in real marginal costs, firms raise their prices and inflation exceeds its steady state value. The central bank increases the nominal interest rate, which causes households to reduce their current real money holdings via a standard money demand function. Furthermore, an active interest rate setting implies an increase in the expected real interest rate. When predetermined real money balances are a state variable, the current growth rate (not the expected growth rate as in an end-of-period formulation) of real money balances is negatively related to the real interest rate. An increase in the real interest rate thus induces households to further reduce their current real money holdings and real money balances do not converge to the steady state. Due to real balance effects, other endogenous variables such as consumption and inflation do not converge to the steady state either.

Our analytical characterization of the set of determinate and indeterminate locally stable equilibrium sequences allows us to estimate the model by Bayesian model estimation techniques as suggested by Lubik and Schorfheide (2004). As observable variables we employ real GDP, inflation, real private consumption, the nominal interest rate, real wages and real money balances for the U.S. from 1964 to 2008. We split the whole sample into the pre-Volcker era (1964–1979) and the time after the disinflation years (post 1982).

We find a decreasing role of money in transactions. In the pre-Volcker era, we estimate an important role for money in transactions, a passive interest rate policy, and determinate equilibrium sequences. After the disinflation years, a determinate cashless economy with an active interest rate setting prevails. Thus, the decreasing role of money in transactions provides an explanation for the switch in the interest rate policy from a passive to an active setting in the United States.

Related Literature Ireland (2004), Canova and Menz (2011) and Castelnuovo (2012) also investigated the role of money in the business cycle. Similar to us, they found that the importance of money for explaining business cycle fluctuations has declined (Canova and Menz, 2011; Castelnuovo, 2012) and that money played only a minor role after the disinflation years (Ireland, 2004). In these papers, however, money demand is specified in a way such that active policy is always necessary for determinacy, irrespective of the importance of money in transactions. Thus they do not explain the switch in interest rate policy. Bilbiie and Straub (2010) provided an alternative explanation for the passive interest rate policy in the pre-Volcker era. Since their economy is cashless, they cannot accommodate the well documented change in the role of money (Schreft and Smith, 2000; Friedman and Kuttner, 1992; Canova and Menz, 2011; Castelnuovo, 2012). In our approach, we connect the changing role of money to the conduct of monetary policy.

We are not the first to analyze equilibrium determination with interest rate feedback rules and real balance effects (e.g. Sims, 1994; Benhabib, Schmitt-Grohé, and Uribe, 2001a; Kurozumi, 2006; Stoltenberg, 2012). Sims (1994) employed a money demand that is also motivated by real resource costs of transactions to globally analyze the dependency of price-level determination on the stance of fiscal policy. Benhabib, Schmitt-Grohé, and Uribe (2001a) were among the first to show that conditions for local stability and uniqueness under an interest rate policy are highly sensitive to changes in preferences and technology. Both papers, however, employed specifications that did not allow real money balances to become a state variable which is the main driving force behind our results.

For the case of flexible prices, Stoltenberg (2012) theoretically analyzed the implications of real money balances as a state variable on price level determination and equilibrium determinacy in a Money-in-the-Utility Function model. As the main distinction to his paper, we consider the empirically more relevant case of sticky prices which fundamentally alters the determinacy analysis. In contrast to Kurozumi (2006) and Stoltenberg (2012), we provide a complete analytical characterization of the set of equilibrium sequences of real money balances as a state variable. In particular, we discriminate between determinate oscillatory and non-oscillatory equilibrium sequences, indeterminate and explosive equilibrium sequences which is necessary to apply the estimation method of Lubik and Schorfheide (2004).

The remainder of the paper is organized as follows. In the next section, we describe the economic environment and analyze the model in Section 3. We present our econometric strategy in Section 4 and our estimation results in Section 5. The last section concludes.

2 Economic Environment

The economy is populated by a continuum of infinitely-lived households indexed by $j \in [0,1]$ that have identical initial asset endowments and identical preferences. Household j acts as a monopolistic supplier of labor services l_j. Financial markets are complete. At the beginning of period t, households' financial wealth comprises a portfolio of state-contingent claims on other households, yielding a (random) payment $\mathcal{X}_{jt}$, and one-period nominally non-state-contingent government bonds B_{jt-1} carried over from the previous period. In period t, a random payoff $\mathcal{X}_{jt+1}$ that materializes period $t+1$ is priced by $\mathbb{E}_t[q_{t,t+1}\mathcal{X}_{jt+1}]$. Thereby, $q_{t,t+1}$ denotes the period-t price of a claim to one unit of currency in a particular state of period $t+1$ divided by the probability of occurrence of that state conditional on information available in period t. The budget constraint of household j is given by the following expression

$$\begin{aligned} M_{jt} + B_{jt} + \mathbb{E}_t[q_{t,t+1}\mathcal{X}_{jt+1}] + P_t c_{jt} + P_t \phi(c_{jt}, z_t M_{jt-1}/P_t) \\ \leq M_{jt-1} + R_{t-1}B_{jt-1} + \mathcal{X}_{jt} + P_t w_{jt} l_{jt} + \int_0^1 D_{jit}\mathrm{d}i - P_t \tau_t, \quad (1) \end{aligned}$$

where c_t denotes a Dixit–Stiglitz aggregate of consumption with elasticity of substitution ς, and M_{jt} end-of-period nominal balances. Further, P_t is the aggregate price level, w_{jt} the real wage rate for labor services l_{jt} of type j, τ_t a lump-sum tax, R_t the gross nominal interest rate on government bonds and D_{jit} dividends from monopolistically competitive firms indexed by i. As in Feenstra (1986), we assume that purchasing consumption goods is costly and that these real resource costs of transactions are captured in the function $\phi(c_{jt}, h_{jt}) \geq 0$, with the argument $h_{jt} = z_t M_{jt-1}/P_t$ as effective real money balances, i.e., real money balances M_{jt-1}/P_t augmented with a mean-one shock to the transaction-cost technology z_t. Besides $\phi(0,h) = 0$, we assume that transaction costs increase in consumption ($\phi_c \geq 0$) and decrease strictly in effective real money balances ($\phi_h < 0$). Marginal transaction costs of consumption are assumed to be non-increasing in effective real money balances ($\phi_{ch} \leq 0$), and non-decreasing in consumption ($\phi_{cc} \geq 0$). Marginal resource gains of holding money are strictly decreasing ($\phi_{hh} > 0$).[2]

Our formulation of the transaction friction is closely related to the Baumol–Tobin cash inventory model (Baumol, 1952; Tobin, 1956; Alvarez and Lippi, 2009; Lippi and Secchi, 2009). To recognize this relationship, consider the following parametric example

$$\phi(c, h) = \iota \frac{c}{h},$$

where in the language of the Baumol–Tobin model, c/h is the number of trips to the bank and ι measures the costs per trip to the bank in terms of goods.

We follow Svensson (1985) and assume that beginning-of-period money balances, M_{t-1}, provide transaction services. This assumption corresponds to a timing of markets within one period where the goods market is closed before the asset market is opened (see also Woodford, 1990; McCallum and Nelson, 1999; Persson, Persson, and Svensson, 2006). The timing of markets is illustrated in Figure 1.

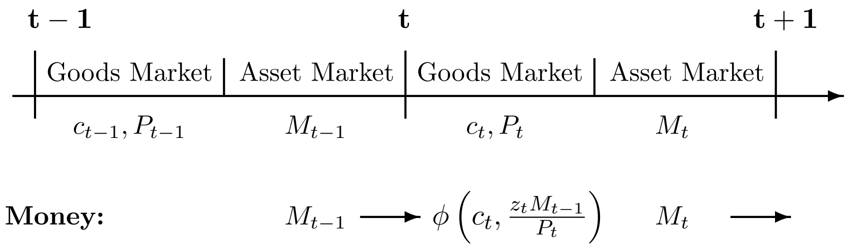

Figure 1: Timing of markets with real resource costs of transactions

The objective of household j is given by the following:

$$\mathbb{E}_{t_0} \sum_{t=t_0}^{\infty} \beta^t [u(c_{jt}, \nu_t) - v(l_{jt})], \tag{2}$$

where $\beta \in (0, 1)$ denotes the subjective discount factor. The instantaneous utility function is assumed to be non-decreasing in consumption, decreasing in labor time, strictly concave, twice differentiable, and to fulfill the Inada conditions for any realization of the taste shock ν_t. The taste shocks exhibits a mean of 1. To avoid additional complexities, we set $u_c = u_{c\nu}$ at the deterministic steady state. Furthermore, consumption and real money balances are

[2] The assumptions $\phi_h < 0$ and $\phi_{hh} > 0$ ensure that the demand for money is decreasing in the nominal interest rate.

normal goods.[3] Households are wage-setters supplying differentiated types of labor l_{jt}, which are transformed into aggregate labor l_t with $l_t^{(\varpi_t-1)/\varpi_t} = \int_0^1 l_{jt}^{(\varpi_t-1)/\varpi_t}\mathrm{d}j$. We assume that the elasticity of substitution between different types of labor, $\varpi_t > 1$, varies exogenously over time. Cost minimization implies that the demand for differentiated labor services l_{jt} is given by $l_{jt} = (w_{jt}/w_t)^{-\varpi_t} l_t$, where the aggregate real wage rate w_t is given by $w_t^{1-\varpi_t} = \int_0^1 w_{jt}^{1-\varpi_t}\mathrm{d}j$. Households are further subject to a borrowing constraint that prevents them from engaging in Ponzi schemes.

The final consumption good y_t is an aggregate of differentiated goods produced by monopolistically competitive firms indexed $i \in [0,1]$ and defined as $y_t^{\frac{\varsigma-1}{\varsigma}} = \int_0^1 y_{it}^{\frac{\varsigma-1}{\varsigma}}\mathrm{d}i$, with $\varsigma > 1$. Let P_{it} denote the price of good i set by firm i. The demand for each differentiated good is $y_{it}^d = (P_{it}/P_t)^{-\varsigma} y_t$, with $P_t^{1-\varsigma} = \int_0^1 P_{it}^{1-\varsigma}\mathrm{d}i$. A firm i produces good y_i using a technology that is linear in the labor bundle $l_{it} = [\int_0^1 l_{jit}^{(\varpi_t-1)/\varpi_t}\mathrm{d}j]^{\varpi_t/(\varpi_t-1)}$: $y_{it} = a_t l_{it}$, where $l_t = \int_0^1 l_{it}\mathrm{d}i$ and a_t is a productivity shock with mean 1. The labor demand satisfies: $\psi_{it} = w_t/a_t$, where $\psi_{it} = \psi_t$ denotes real marginal costs independent of the quantity that is produced by the firm. We allow for a nominal rigidity in the form of a staggered price setting as developed by Calvo (1983). Each period, firms may reset their prices with probability $1-\alpha$ independently of the time elapsed since the last price setting. A fraction $\alpha \in [0,1)$ of firms is assumed to adjust prices according to the simple rule $P_{it} = \bar{\pi} P_{it-1}$, where $\bar{\pi}$ denotes the average inflation rate. In each period, a measure $1-\alpha$ of randomly selected firms set new prices $\widetilde{P}_{it}$ as the solution to

$$\max_{\widetilde{P}_{it}} \mathbb{E}_t \sum_{s=0}^{\infty} \alpha^s q_{t,t+s}(\bar{\pi}^s \widetilde{P}_{it} y_{it+s} - P_{t+s}\frac{w_{t+s}}{a_{t+s}} y_{it+s}), \quad s.t.\ y_{it+s} = (\widetilde{P}_{it}\bar{\pi}^s)^{-\varsigma} P_{t+s}^{\varsigma} y_{t+s}, \tag{3}$$

where we assume that firms have access to contingent claims.

The central bank as the monetary authority is assumed to control the short-term interest rate R_t with the following simple feedback rule contingent on inflation:

$$R_t = f(\pi_t, r_t^m) \quad with \quad f_\pi > 0, \tag{4}$$

where r_t^m is a monetary policy shock with mean 1. We further assume that the steady-state condition $R = \pi/\beta$ has a unique solution for $R > 1$. The consolidated government budget constraint is given by the expression $M_{t-1} + R_{t-1}B_{t-1} + P_t g_t = M_t + B_t + P_t \tau_t$. The exogenous government expenditures g_t evolve around a mean $\bar{g}$, which is restricted to be a constant fraction

[3] Formally, this requires: $\phi_{hh}[\phi_{cc}u_c/(1+\phi_c) - u_{cc}] - u_c/(1+\phi_c)\phi_{ch}\phi_{hc} > 0$.

of steady-state output, $\bar{g} = \bar{y}(1 - s_{\mathrm{C}})$. Here, s_{C} in (0,1] denotes the average output share of private consumption. We assume that tax policy τ_t guarantees government solvency.

The aggregate resource constraint is given by

$$y_t = a_t l_t / \Delta_t, \tag{5}$$

where $\Delta_t = \int_0^1 (P_{it}/P_t)^{-\varsigma} \mathrm{d}i \geq 1$ is a term capturing price dispersion.

Clearing the goods market requires

$$c_t + g_t + \phi(c_t, h_t) = y_t. \tag{6}$$

We collect the exogenous disturbances in the vector $\xi_t = [a_t, g_t, \mu_t, \nu_t, z_t, r_t^m]'$, where $\mu_t = \frac{\varpi_t}{\varpi_t - 1}$ is a wage mark-up shock. The percentage deviations from the means of the first 5 elements in vector ξ evolve according to autonomous AR(1)-processes with autocorrelation coefficients $\rho_a, \rho_g, \rho_\mu, \rho_\nu, \rho_z \in [0, 1)$. The process for $\log(r_t^m)$ and all innovations, $\epsilon_t = [\epsilon_t^a, \epsilon_t^g, \epsilon_t^\mu, \epsilon_t^\nu, \epsilon_t^z, \epsilon_t^m]'$, are assumed to be i.i.d.

The recursive equilibrium is defined as follows:

Definition 1 *Given the initial values P_{t_0-1}, Δ_{t_0-1}, M_{t_0-1}, $R_{t_0-1}B_{t_0-1}$, a monetary policy (4), and a Ricardian fiscal policy τ_t $\forall\, t \geq t_0$, a rational expectations equilibrium for $R_t \geq 1$ is a set of sequences $\{y_t,\, c_t,\, l_t,\, m_t,\, \psi_t,\, w_t,\, \Delta_t,\, P_t,\, \widetilde{P}_{it}, R_t\}_{t=t_0}^{\infty}$ for $\{\xi_t\}_{t=t_0}^{\infty}$*

(i) that maximizes households' utility (2) s.t. their budget constraints (1),

(ii) that solves the firms' problem (3) with $\widetilde{P}_{it} = \widetilde{P}_t$,

(iii) that satisfies the aggregate resource constraint (5) and clears the goods market(6),

(iv) and that fulfills the transversality condition $\lim_{n\to\infty} \mathbb{E}_t\, \beta^n \lambda_{t+n}(M_{t+n} + B_{t+n} + \mathcal{X}_{t+1+n})/P_{t+n} = 0$, where λ_t is the Lagrange multiplier on (1).

3 Model Analysis

In this section, we derive the conditions that describe households' optimal behavior. In the next step, we apply log-linear approximations to the true non-linear equilibrium equations and analyze the equilibrium properties in the neighborhood of the deterministic steady state.

3.1 First-Order Conditions and Log-Linear Approximation

Maximizing (2) with respect to (1) leads to the following set of equations describing households' optimal choices for consumption, labor and real money balances:

$$v_l(l_{jt})\mu_t(1+\phi_c(c_{jt}, z_t m_{jt-1}/\pi_t)) = w_t u_c(c_{jt}, \nu_t), \tag{7}$$

$$\frac{u_c(c_{jt}, \nu_t)}{1+\phi_c(c_{jt}, z_t m_{jt-1}/\pi_t)} = \beta R_t \,\mathbb{E}_t \frac{u_c(c_{jt+1}, \nu_{t+1})}{1+\phi_c(c_{jt}, z_{t+1} m_{jt}/\pi_{t+1})}/\pi_{t+1}, \tag{8}$$

$$(R_t - 1)\,\mathbb{E}_t \frac{u_c(c_{jt+1}, \nu_{t+1})}{(1+\phi_c(c_{jt}, z_{t+1} m_{jt}/\pi_{t+1}))\,\pi_{t+1}} = - \,\mathbb{E}_t\, z_{t+1} \frac{\phi_h(c_{jt+1}, z_{t+1} m_{jt}/\pi_{t+1}) u_c(c_{jt+1}, \nu_{t+1})}{(1+\phi_c(c_{jt}, z_{t+1} m_{jt}/\pi_{t+1}))\,\pi_{t+1}}, \tag{9}$$

where $m_t = M_t/P_t$. Real marginal transaction costs ϕ_c influence both the intra-temporal and the inter-temporal optimal consumption choices. On the one hand, they drive a wedge between the marginal utility of the cash good consumption and the credit good leisure (7). On the other hand, the accumulation of real money balances contributes to the dynamic evolution of marginal transaction costs and, thus, shapes the optimal consumption path (8). Finally, real transaction costs give also rise to a money demand function that is increasing in expected consumption expenditures and decreasing in the nominal interest rate (9).

The set of first order conditions of the private sector is completed by the optimal pricing condition of monopolistically competitive firms who can adjust prices. In the symmetric equilibrium, the condition is given by the following expression

$$\widetilde{P}_t = \frac{\varsigma}{\varsigma - 1} \frac{\mathbb{E}_t \sum_{s=0}^{\infty} \alpha^s \left(q_{t,t+s} y_{t+s} \bar{\pi}^{-\varsigma s} P_{t+s}^{\varsigma+1} \frac{w_{t+s}}{a_{t+s}} \right)}{\mathbb{E}_t \sum_{s=0}^{\infty} \alpha^s \left(q_{t,t+s} y_{t+s} \bar{\pi}^{(1-\varsigma)s} P_{t+s}^{\varsigma} \right)}. \tag{10}$$

In the following, we focus on the model's behavior in the neighborhood of its deterministic steady state, which is characterized by the following properties: $f(\pi, 1) = \pi/\beta$, $v_l[c + g + \phi(c, m/\pi)]\mu[1 + \phi_c(c, m/\pi)] = u_c(c)(\varsigma - 1)/\varsigma$, and $f(\pi, 1) = 1 - \phi_h(c, m/\pi)$. Combining optimal private sector behavior (7)-(10) with the aggregate resource constraint (5) and goods market clearing (6), the set of equilibrium sequences for consumption, output, inflation, interest, wages and real money balances must satisfy:

$$\tilde{\sigma}\,\mathbb{E}_t\,\widehat{c}_{t+1} - \mathbb{E}_t\,\widehat{\nu}_{t+1} - \eta_{ch}(\widehat{m}_t - \mathbb{E}_t\,\widehat{\pi}_{t+1} + \mathbb{E}_t\,\widehat{z}_{t+1}) = \tilde{\sigma}\widehat{c}_t - \widehat{\nu}_t - \eta_{ch}(\widehat{m}_{t-1} - \widehat{\pi}_t + \widehat{z}_t) + \widehat{R}_t - \mathbb{E}_t\,\widehat{\pi}_{t+1}, \tag{11}$$

$$\omega(\widehat{y}_t - \widehat{a}_t) + \widehat{\mu}_t - \widehat{w}_t = -\tilde{\sigma}\widehat{c}_t + \eta_{ch}(\widehat{m}_{t-1} - \widehat{\pi}_t + \widehat{z}_t) + \widehat{\nu}_t, \tag{12}$$

$$\widehat{\pi}_t = \beta\,\mathbb{E}_t\,\widehat{\pi}_{t+1} + \kappa(\widehat{w}_t - \widehat{a}_t), \tag{13}$$

$$\widehat{y}_t = s_{\mathrm{C}}\widehat{c}_t + \widehat{g}_t, \tag{14}$$

$$\widehat{m}_t = -\eta_R\widehat{R}_t + \frac{\eta_{hc}}{\sigma_h}\,\mathbb{E}_t\,\widehat{c}_{t+1} + \mathbb{E}_t\,\widehat{\pi}_{t+1} + \frac{1-\sigma_h}{\sigma_h}\,\mathbb{E}_t\,\widehat{z}_{t+1}, \tag{15}$$

where $\sigma_c = -u_{cc}c/u_c$, $\omega = v_{ll}l/v_l$, $\kappa = (1-\alpha)(1-\alpha\beta)/\alpha$, $\eta_{ch} = -\phi_{ch}h/(1+\phi_c)$, $\eta_{hc} \equiv \phi_{hc}c/\phi_h$, $\eta_R = \frac{R}{\sigma_h(R-1)}$, $\sigma_h = -\phi_{hh}h/\phi_h$, and $\tilde{\sigma} = \sigma_c + \eta_{cc}$, with $\eta_{cc} = \phi_{cc}c/(1+\phi_c)$.

Furthermore, $\widehat{x}_t$ denotes the percentage deviation of a generic variable x_t from its steady-state value x. In the case of government expenditures, $\widehat{g}_t = (g_t - g)/y$ denote deviations relative to steady-state output. In approximating the aggregate resource constraint, we assume that real transaction costs are of second order or higher, i.e., $\phi(c_t, h_t) = \mathcal{O}(\|\xi_t\|^2)$.[4] Equation (15) is a money demand equation; real money balances react negatively to changes in the nominal interest rate and positively to changes in expected consumption and inflation. The model is closed by a simple Taylor rule as an approximation to Equation (4):

$$\widehat{R}_t = \rho_\pi\widehat{\pi}_t + \varepsilon_t^m, \tag{16}$$

with $\rho_\pi \equiv f_\pi(\pi, 1)\pi/R$.

We argue that the cross derivative η_{ch} is a reasonable way to capture transaction frictions and the importance of money. First, for $\eta_{ch} = 0$, the dynamic system reduces to the standard cashless economy in the sense that the equilibrium sequences for consumption, inflation, output, real wages and the nominal interest rate are independent of real money balances. Further, predetermined real money balances do not serve as a state variable. In this case, the primary role of money is to serve as a unit of account rather than to influence consumption expenditures. A second reason follows from the close relation to the Baumol–Tobin cash inventory model, in which the costs of withdrawals ι is the key parameter. As shown by Alvarez and Lippi (2009), this parameter is a natural candidate to investigate developments in withdrawal technology, such as the increasing diffusion of bank branches and ATM terminals. Decreases in the elasticity η_{ch} can be interpreted as decreases in the fixed costs of withdrawals. To see this, consider a general

[4] While the assumption simplifies our analytical characterization of equilibrium sequences, it is not key for our analysis. In Appendix E, we provide robustness results for the case of transaction costs that are of first order and therefore appear as part of the right-hand side of (14).

resource-cost function that is linear in ι, $\phi(c,h) = \iota g(c,h)$. Given data for real money balances and consumption and a functional form for $g(c,h)$, we can express η_{ch} as a function of ι:

$$\eta_{ch} \equiv \frac{-\phi_{ch} h}{1+\phi_c} = \frac{-\iota g_{ch}(c,h)h}{1+\iota g_c(c,h)}.$$

This expression implicitly defines ι as a strictly monotonically increasing function in η_{ch}.[5] In Section 5, we provide direct evidence that the fixed costs of withdrawals ι decreased in the United States. We continue the analysis of our model with an analytical characterization of the conditions for local stability and uniqueness of equilibrium sequences.

3.2 Analytical Characterization of Equilibrium Sequences

When the transaction friction matters ($\eta_{ch} > 0$), the model with the real resource costs of transactions features predetermined real money balances $\widehat{m}_{t-1}$ as an endogenous state variable. The following proposition states the conditions for local stability and also distinguishes between 3 regions of locally unique and locally indeterminate equilibrium sequences.

Proposition 1 *Consider $\eta_{ch} > 0$. The equilibrium displays local stability if and only if*

(i) $\rho_\pi \geq 1$ for $\eta_{ch} \leq \bar{\eta}_{ch}$, and $1 \leq \rho_\pi < \bar{\rho}_\pi(\eta_{ch})$ for $\eta_{ch} > \bar{\eta}_{ch}$, leading to locally unique and oscillatory equilibrium sequences (Region 1, $\mathcal{R}1$), or

(ii) $\rho_\pi < \min[1, \bar{\rho}_\pi(\eta_{ch})]$ for $\eta_{ch} > \bar{\eta}_{ch}$ and $\rho_\pi < 1$ for $\eta_{ch} \leq \bar{\eta}_{ch}$, leading to locally indeterminate equilibrium sequences (Region 2, $\mathcal{R}2$), or

(iii) $\bar{\rho}_\pi(\eta_{ch}) \leq \rho_\pi < 1$ for $\eta_{ch} > \bar{\eta}_{ch}$, leading to locally unique and non-oscillatory equilibrium sequences (Region 3, $\mathcal{R}3$);

with $\bar{\rho}_\pi(\eta_{ch}) \equiv \frac{[2(1+\beta)+\kappa]\Upsilon(\eta_{ch})+\omega\kappa\sigma_h}{\kappa[2\eta_{ch}z\omega-\Upsilon(\eta_{ch})-\sigma_h\omega]}$ as a decreasing function of η_{ch} with $\Upsilon(\eta_{ch}) \equiv \tilde{\sigma}_y\sigma_h - \eta_{ch}\eta_{hc}/s_{\mathrm{C}} > 0$, $\bar{\eta}_{ch} \equiv \frac{\sigma_h(\tilde{\sigma}_y+\omega)}{2zw+\eta_{hc}/s_{\mathrm{C}}}$, $\tilde{\sigma}_y \equiv \tilde{\sigma}/s_{\mathrm{C}}$, and $z \equiv R/(R-1)$.

The proof can be found in Appendix A.

The case when $\eta_{ch} = 0$ has been analyzed by Woodford (2003) in Chapter 4 Proposition 4.3. Woodford showed that the set of equilibrium sequences displays local stability and uniqueness if and only if $\rho_\pi \geq 1$. We refer to this case as *Region* 4 ($\mathcal{R}4$). Further, if and only if $\rho_\pi < 1$, the

[5] Using the implicit function theorem, the derivative of ι with respect to η_{ch} is given by $-[1+\iota g_c(c,h)]^2/[g_{ch}(c,h)h] > 0$ for $\iota g_{ch} = \phi_{ch} < 0$.

set of equilibrium sequences is locally stable and indeterminate which we refer to as *Region* 5 ($\mathcal{R}5$).

Proposition 1 summarizes three different regions of locally stable equilibrium sequences for $\eta_{ch} > 0$ depending on the size of the transaction friction and the stance of interest policy. The regions follow from the intersection of the function $\bar{\rho}(\eta_{ch})$ with the unit line in a (ρ_π, η_{ch}) space. Figure 2 provides a graphical illustration of the proposition.[6]

When the transaction friction is sufficiently large ($\eta_{ch} > \bar{\eta}_{ch}$), only a passive interest policy ($\rho_\pi < 1$) achieves a stable and unique set of equilibrium sequences (*Region* 3). Further, the equilibrium sequences are non-oscillatory. In *Region* 1, the Taylor-principle holds but results in oscillatory equilibrium paths. When the transaction friction vanishes, the economy collapses to a purely forward-looking cashless economy, where only the Taylor principle ensures stability and uniqueness of equilibrium sequences (*Region* 4).

The main message of this proposition is that if the transaction friction η_{ch} is sufficiently large ($\eta_{ch} > \bar{\eta}_{ch}$), then local stability and uniqueness of non-oscillatory equilibrium sequences requires a passive monetary policy ($\rho_\pi < 1$). In other words, the Taylor principle does not constitute a stabilizing advice in *Region* 3 and even results in explosive (and not just locally indeterminate as in Benhabib, Schmitt-Grohé, and Uribe (2001a)) equilibrium sequences.

To see why the Taylor principle can induce explosive equilibrium sequences, suppose that an adverse technology shock occurs and that equilibrium sequences are non-oscillatory. As a reaction to the increase in real marginal costs, firms raise their prices and inflation exceeds its steady state value. Since the inflation elasticity is positive, $\rho_\pi > 0$, the central bank increases the nominal interest rate, which ceteris paribus causes households to reduce their end-of-period real money holdings $\widehat{m}_t$, by Equation (15). According to Equation (11), the expected real interest rate, $r_t = \widehat{R}_t - \mathbb{E}_t \widehat{\pi}_{t+1}$, is negatively related to the growth rate of real money balances. Thus, an active interest rate setting, $\rho_\pi > 1$, leads to a decline in the level and the growth rate of real money balances, such that the sequences of real balances and, thus, of output and inflation do not converge to the steady state. The interest policy reaction should however not be too mild to prevent indeterminate equilibrium sequences ($\bar{\rho}_\pi < \rho_\pi < 1$) that occur in *Region* 2.

[6] The parameter values employed here are the prior mean and calibrated parameters that are described in detail in Section 4.

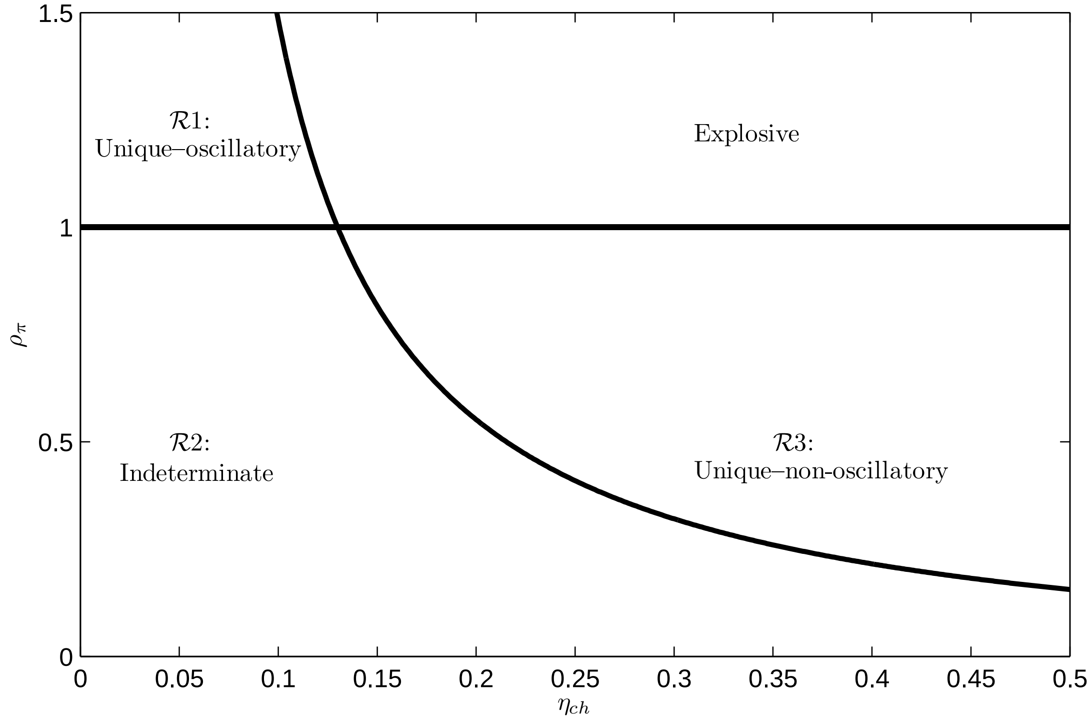

Figure 2: Stability and uniqueness of equilibrium sequences for $\eta_{ch} > 0$.

Proposition 1 does address not only stability considerations but also implies recommendations for optimal policy. When transaction frictions are sufficiently large ($\eta_{ch} > \bar{\eta}_{ch}$), the Taylor principle is not an optimal policy device because it results in explosive paths for all endogenous variables.

3.3 Impulse–Response Analysis

The short-run dynamics in *Region* 3 are very different from the corresponding reactions in the cashless *Region* 4. Consider an innovation to government expenditures as displayed in Figure 3. On impact, private consumption is crowded out and labor supply increases. Together with the increase in aggregate demand it facilitates an increase in output. To return to the steady state, consumption growth must be positive, which requires a rise in the real interest rate according to the Euler equation (11). In *Region* 3 with a passive interest rate policy, this necessitates a fall in inflation such that the nominal interest rate decreases, and output and inflation are negatively correlated. In the cashless *Region* 4 with an active interest rate setting, an increase in the real interest rate is achieved by an increase in inflation. Output and inflation are then positively correlated.

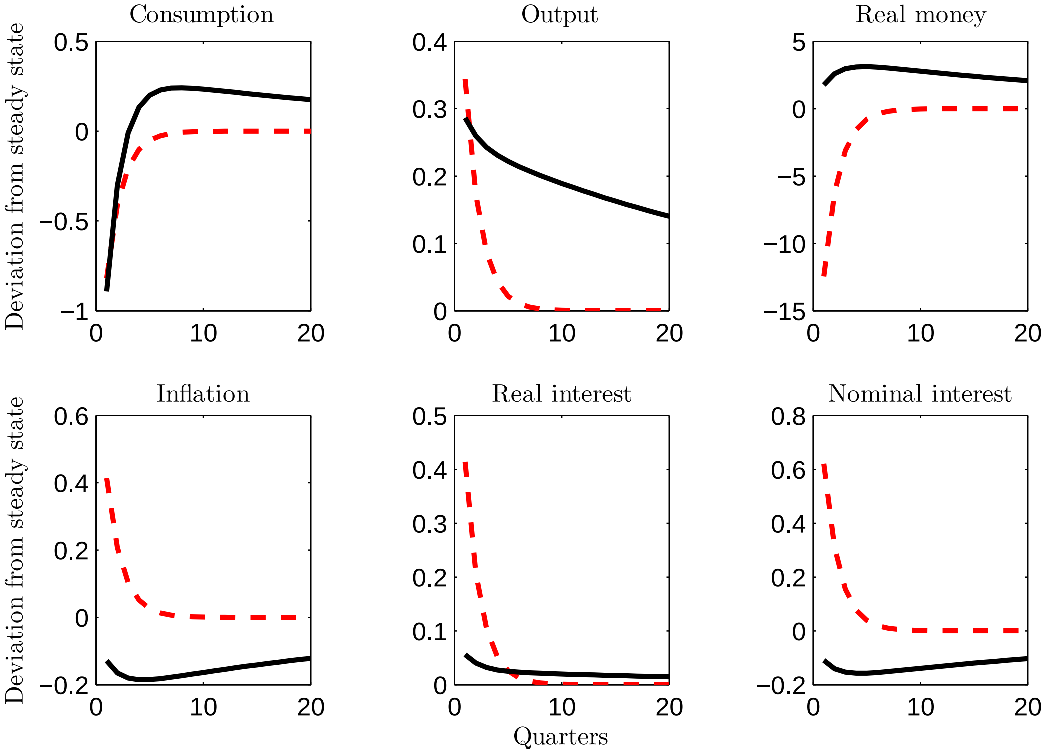

Figure 3: Impulse respones to a one percent innovation in government expenditures in the cashless region $\mathcal{R}4$ (dashed-red) and in the monetary region $\mathcal{R}3$ (solid-black). Prior mean.

4 Data and Econometric Strategy

In this section, we describe the data and our econometric strategy to estimate the parameters of the model.

4.1 Data

We employ real output per capita, real consumption per capita, annual inflation, the federal funds rate, real money balances based on M2, and real wages as observable variables. To check the robustness of our results, we also estimate the model using M1 as a monetary aggregate instead of M2.[7]

In our baseline estimation, we de-trend the data before estimating the regions by removing a linear quadratic time trend. To ensure robustness of our estimates with respect to the way we de-trend the data, we repeat the estimation of the regions, but de-trend real GDP, real consumption, real money balances, and real wages using a one-sided HP filter.[8]

The quarterly observations range from the first quarter of 1964 to the second quarter of

[7] A complete description of the data set and its sources can be found in Appendix C.
[8] We initialize the one-sided HP filter using five quarters.

2008. For our purpose and as is commonly done (Lubik and Schorfheide, 2004; Clarida, Galí, and Gertler, 2000), we split the sample into two parts: the first sample S_1 represents the pre-Volcker period and runs from the first quarter of 1964 to the fourth quarter of 1978. We exclude the disinflation years and start the second sample S_2 from the first quarter of 1983 and include data until the second quarter of 2008.

4.2 Estimation strategy

We employ Bayesian estimation techniques to estimate the model. We denote the vector of deep parameters by θ and the data by Y_T. In our estimation strategy, we follow Lubik and Schorfheide (2004). Proposition 1 assigns one region i to one combination of parameters, $i = 1, 2 \ldots 5$. We define an indicator function $f(\theta) = \{\theta \in \Theta^{\mathcal{R}i}\}$ which is one if $\theta \in \Theta^{\mathcal{R}i}$, and zero otherwise. We decompose the likelihood function of the model $p(Y_T|\theta)$ in the sum of the different likelihood functions of the different regions $p_{\mathcal{R}i}(Y_T|\theta)$

$$p(Y_T|\theta) = \left[\sum_{i=1}^{5} \{\theta \in \Theta^{\mathcal{R}i}\} p_{\mathcal{R}i}(Y_T|\theta) \right].$$

The posterior distribution of θ, $p(\theta|Y_T)$, can thus be written as:

$$p(\theta|Y_T) = \frac{\left[\sum_{i=1}^{5} \{\theta \in \Theta^{\mathcal{R}i}\} p_{\mathcal{R}i}(Y_T|\theta) \right] p(\theta)}{p(Y_T)},$$

where $p(\theta)$ denotes the prior distribution of θ, and $p(Y_T)$ the marginal data density of the model. Lubik and Schorfheide (2004) consider only two different regions. In their case, it is straightforward to define a prior distribution such that both regions exhibit equal prior probabilities. This is not possible in our setup with five regions. Instead, we define a prior distribution for each region, $p_{\mathcal{R}i}(\theta)$. This poses a challenge to our analysis because, as in Lubik and Schorfheide (2004), we determine which region is favored by the data based on the posterior probability of each region. This statistic is influenced by the prior distribution. In the following, we describe the challenge in detail and how we account for it.

We start by defining the weight each region receives after the estimation. This is the marginal data density of region i:

$$p_{\mathcal{R}i}(Y_T) = \int_{\Theta} \{\theta \in \Theta^{\mathcal{R}i}\} p_{\mathcal{R}i}(Y_T|\theta) p_{\mathcal{R}i}(\theta) d\theta. \quad (17)$$

According to (17), the marginal data density of region i is the weighted average of the likelihood estimates of θ with the prior distribution of θ as weights. Thus, the choice of the prior distribution affects the marginal data density: a prior distribution allocating high (low) probability mass in the same area as the likelihood increases (decreases) the marginal data density.

To take the influence of the prior distribution into account, we employ the training sample method suggested by Sims (2003). The training sample method divides the whole sample Y_T into two subsamples: $Y_{T,1}$ and the training sample $Y_{T,0}$.[9] Correspondingly, the product of the likelihood and the prior distribution of each region i, $p_{\mathcal{R}i}(Y_T|\theta)p_{\mathcal{R}i}(\theta)$, can be written as

$$p_{\mathcal{R}i}(Y_T|\theta)p_{\mathcal{R}i}(\theta) = p_{\mathcal{R}i}(Y_{T,1}|Y_{T,0}\theta,)p_{\mathcal{R}i}(Y_{T,0}|\theta)p_{\mathcal{R}i}(\theta).$$

We divide both sides by the marginal data density of the training sample:

$$p_{\mathcal{R}i}(Y_{T,0}) = \int_{\Theta} \{\theta \in \Theta^{\mathcal{R}_i}\} p_{\mathcal{R}i}(Y_{T,0}|\theta)p_{\mathcal{R}i}(\theta)d\theta, \tag{18}$$

to obtain

$$\frac{p_{\mathcal{R}i}(Y_T|\theta)p_{\mathcal{R}i}(\theta)}{p_{\mathcal{R}i}(Y_{T,0})} = p_{\mathcal{R}i}(Y_{T,1}|Y_{T,0},\theta)\left[\frac{p_{\mathcal{R}i}(Y_{T,0}|\theta)p_{\mathcal{R}i}(\theta)}{p_{\mathcal{R}i}(Y_{T,0})}\right].$$

The training sample method interprets the term $\left[\frac{p_{\mathcal{R}i}(Y_{T,0}|\theta)p_{\mathcal{R}i}(\theta)}{p_{\mathcal{R}i}(Y_{T,0})}\right]$ as the prior distribution for the likelihood $p_{\mathcal{R}i}(Y_{T,1}|Y_{T,0}\theta)$. Note that

$$\int_{\Theta} \{\theta \in \Theta^{\mathcal{R}i}\} \left[\frac{p_{\mathcal{R}i}(Y_{T,0}|\theta)p_{\mathcal{R}i}(\theta)}{p_{\mathcal{R}i}(Y_{T,0})}\right] d\theta = 1. \tag{19}$$

According to (19), each region therefore exhibits the same prior probability after the training sample. Hence, applying the training sample method prevents the manipulation of the marginal data density of each region by choosing prior distributions. Consequently, the marginal data density of each region is not influenced by the fact that the prior distribution allocates different prior probabilities to different regions. Instead, the resulting posterior probabilities of the regions are only driven by the additional evidence provided by the data $Y_{T,1}$. In our analysis, we report the marginal data density of region i corrected by the marginal data density of the

[9] We choose a training sample of 20 quarters for the first subsample S_1. Since we have a longer sample available in S_2, we choose a training sample of 30 quarters.

training sample (18). The corrected marginal data density is given by the following expression

$$\tilde{p}_{\mathcal{R}i}(Y_{T,1}) = \frac{\int_{\Theta}\{\theta \in \Theta^{\mathcal{R}i}\}p_{\mathcal{R}i}(Y_T|\theta)p_{\mathcal{R}i}(\theta)d\theta}{p_{\mathcal{R}i}(Y_{T,0})} \tag{20}$$

The posterior probability of region i, our key statistic, is defined as the ratio of the marginal data densities of the region over the sum of the marginal data densities of all regions:

$$\pi_{\mathcal{R}i} = \frac{\tilde{p}_{\mathcal{R}i}(Y_{T,1})}{\sum_{j=1}^{5}\tilde{p}_{\mathcal{R}j}(Y_{T,1})}. \tag{21}$$

For each region, sample period, the full sample and the training sample, we employ the following procedure. First, we obtain the estimation results by approximating the posterior mode. Afterwards we employ a random walk Metropolis-Hastings algorithm to evaluate the posterior distribution. Each time, we run two chains, each chain consisting of 500,000 draws. We discard the first 250,000 draws of each chain and compute the reported statistics based on the remaining ones.[10] The marginal data density of each region is then computed based on 250,000 draws using the modified harmonic mean estimator as proposed by Geweke (1999).

4.3 Prior Choice and Calibrated Parameters

We calibrate the discount factor to $\beta = 0.99$ and specify a value of 0.8 for the steady-state fraction of private consumption relative to GDP, s_C. The coefficient of relative risk aversion $\tilde{\sigma}$ is set to 1, and we employ a Frisch elasticity of labor supply of 0.29 ($\omega = 3.5$). The steady state gross nominal interest rate is computed from the data. In the pre-Volcker period, the average quarterly nominal interest rate was $\bar{R} = 1.0146$, and in the period post 1982 it was $\bar{R} = 1.0130$.

In Table 3 in Appendix D, we summarize the specification of the prior distribution. We choose different prior distributions for the coefficient on inflation in the Taylor rule and for the elasticity η_{ch} depending on the region of equilibrium sequences. The prior distribution for ρ_π in *Region* 1, and *Region* 4 is centered around a mean of 1.5. In *Region* 2, *Region* 3 and *Region* 5 the prior distribution features a mean of 0.85. The prior distribution for η_{ch} in *Region* 3 exhibits a mean of 0.3. In *Region* 2 as well as in *Region* 1, we employ prior distributions with smaller means of 0.1 and 0.07, respectively.

The prior distribution for σ_h is chosen to yield a net-interest rate elasticity, $-\partial \log m_t/\partial \log(R_t-$

[10] To check for convergence, we apply the convergence statistics suggested by Brooks and Gelman (1998). The statistics indicate convergence after 100,000 draws for all estimated regions and sample periods.

1), of 0.29 at the mean before Volcker and 0.26 at the mean after the year 1982. This value is in the middle of the U.S. estimates by Lucas (2000), 0.5, for data from 1900 to 1994, and Ireland (2009) who finds a value of 0.09 using data from 1980 to 2006. We choose the mean in the second sample slightly smaller since Ireland (2009) finds a decline in the net-interest rate elasticity. The prior distribution for η_{hc} is chosen to generate a unit output elasticity of money demand at the mean, i.e. $\eta_{hc} = 0.8\sigma_h$.

When estimating the indeterminate equilibrium sequences of the model, we consider two equilibrium selecting assumptions. First, we allow for a different impact reaction to the fundamental shocks. Second, we consider in addition the possibility of an i.i.d. sunspot shock.[11] As in Lubik and Schorfheide (2004), we find the first specification to be weakly preferred over the second specification. Consequently, we employ the specification without sunspot shocks. Details on the exact implementation are provided in Appendix B.

The prior distributions for the remaining parameters are similar to Smets and Wouters (2007) as the benchmark estimation for the U.S. economy. More precisely, the prior distribution for the Calvo parameter is parameterized with a mean of 0.5. The prior distribution for the autoregressive coefficients is centered at 0.5. For the standard deviations of the i.i.d. terms in the shock processes, we choose a prior distribution with a mean of 0.04.

5 Results

In this section, we provide our estimation results on the decreasing role of money in transactions and its implications for interest rate policy. Furthermore, we review direct evidence for decreasing real resource costs of transactions in the United States. The results of several robustness exercises can be found in Appendix E.

5.1 Decreasing Role of Money and its Implications

We start our discussion with the posterior probabilities of the regions in the pre-Volcker period and after 1982. As displayed in Table 1, we find substantial differences between the two periods. In the pre-Volcker era, the set of equilibrium sequences stemming from the determinate monetary *Region* 3 exhibits the highest posterior probability with 0.98; monetary policy is passive and money plays an important role in facilitating transactions as indicated by a value

[11] These procedures do not resolve the indeterminacy of the model. Essentially, the procedures constitute additional restrictions imposed on the solution of the model that are tested empirically.

Table 1: Monetary versus Cashless Region (I)

	Pre-Volcker		Post-1982	
	$\mathcal{R}3$	$\mathcal{R}4$	$\mathcal{R}3$	$\mathcal{R}4$
Log marginal data density, $\log \tilde{p}_{\mathcal{R}i}(Y_{T,1})$	737.57	733.87	1581.44	1609.23
Probability, $\pi_{\mathcal{R}i}$	0.98	0.02	0.00	0.82

Notes: Log marginal data densities and posterior model probabilities for the monetary *Region* 3 and for the cashless *Region* 4 as the most likely regions.

of 0.46 at the posterior mean for η_{ch}. The cashless *Region* 4 exhibits a probability of just two percent. After the disinflation years, the equilibrium sequences in the determinate cashless *Region* 4 without an explicit transaction role for money are most likely with a probability of 0.82. *Region* 1 follows with a posterior probability of 0.18. Equilibrium sequences stemming from this region also feature an active interest rate policy and money plays a negligible role since the estimated value for η_{ch} of 0.0055 at the posterior mean is low. As reflected in the change in the most likely region, we find a decreasing role of money in transactions. In contrast to conventional wisdom, the probability for determinacy ($\sum_{\mathcal{R}1,3,4} \pi_{\mathcal{R}i}$) is almost one also in the pre-Volcker era (see Table 4 in Appendix D).

Although we allow for indeterminacies in our likelihood-based estimation, we find that the changing role for money is the key to understand the change in U.S. monetary policy. Our results do not contradict the findings by Lubik and Schorfheide (2004) who provided evidence that interest rate policy before Volcker resulted in an indeterminate equilibrium. The main difference to their approach is that in our more general model, we allow for a transaction role of money while Lubik and Schorfheide (2004) estimated a cashless economy. Regarded through the lens of their model, a passive interest rate policy inevitably leads to an indeterminate equilibrium. In our model, however, a passive policy may be (but is not necessarily) consistent with determinacy.

In Table 2, we provide the posterior mean estimates for the structural parameters and their 90-percent confidence bands belonging to the region that is most likely in each of the sample periods. We find that the decreasing role of money as indicated by a switch from *Region* 3 in the pre-Volcker period to *Region* 4 after 1982 as the most likely region is accompanied by a change in interest rate policy. While in the pre-Volcker period interest rate policy is best characterized by a passive regime with posterior mean $\rho_\pi = 0.97$, interest rate policy after 1982 is best described by an active regime with posterior mean $\rho_\pi = 2.38$.

Furthermore, we find that money demand's sensitivity with respect to changes in the nominal interest rate has declined over time. While the net-interest rate elasticity at the posterior mean, $-\partial \log m_t / \partial \log(R_t - 1) = 1/\sigma_h$, amounts to 0.24 in the first sample (1964–1979), it falls to 0.12 after the disinflation years. The latter value is consistent with the one found by Ireland (2009) who estimates a value of 0.09 in a regression analysis using U.S. data from 1980 to 2006. Our estimates in the first as well as in the second sample period are lower than the one found by Lucas (2000), 0.5, who employs a different data set ranging from 1900 to 1994. Consistent with the great moderation hypothesis (Galí and Gambetti, 2009), the standard deviations of the i.i.d. terms in the shock processes (σ_ζ) are higher in the first sample period than in the second period.

Table 2: Estimation Results

	Pre-Volcker		Post-1982	
Parameter	Mean	90-percent interval	Mean	90-percent interval
ρ_π	0.9692	[0.9420, 0.9907]	2.3829	[2.1989, 2.5766]
η_{ch}	0.4587	[0.3510, 0.5721]	–	–
η_{hc}	3.0792	[2.4130, 3.7862]	–	–
α	0.3304	[0.2605, 0.3970]	0.6051	[0.5641, 0.6435]
σ_h	4.1656	[3.6423, 4.7117]	8.5090	[7.7512, 9.2882]
ρ_g	0.8535	[0.7896, 0.9146]	0.9472	[0.9261, 0.9672]
ρ_a	0.9221	[0.8789, 0.9621]	0.9883	[0.9800, 0.9953]
ρ_μ	0.8501	[0.8045, 0.8938]	0.8828	[0.8432, 0.9193]
ρ_z	0.8943	[0.8657, 0.9218]	0.9620	[0.9405, 0.9816]
ρ_ν	0.6337	[0.4945, 0.7680]	0.9638	[0.9442, 0.9800[
σ_g	0.0084	[0.0075, 0.0094]	0.0053	[0.0049, 0.0058]
σ_a	0.0068	[0.0060, 0.0076]	0.0044	[0.0040, 0.0048]
σ_μ	0.0417	[0.0367, 0.0470]	0.0188	[0.0156, 0.0221]
σ_z	0.0513	[0.0414, 0.0623]	0.0140	[0.0124, 0.0158]
σ_ν	0.0112	[0.0082, 0.0147]	0.0152	[0.0117, 0.0185]
σ_m	0.0051	[0.0045, 0.0057]	0.0055	[0.0050, 0.0060]

Notes: Posterior estimates of the structural parameters in S_1 for the monetary region ($\mathcal{R}3$) and in S_2 for the cashless region ($\mathcal{R}4$) as the most likely regions.

In a recent paper, Cochrane (2011) questions the identification of estimated parameters in New Keynesian models. To assess the local identification of the estimated parameters, we employ the method suggested by Iskrev (2010). More precisely, we determine whether the Jacobian of the second moments of the observable variables with respect to the vector of parameters has full rank across the posterior distribution.[12] We conduct this test for the two dominating

[12] We choose the variance covariance matrix and three auto-covariance matrices of the observable variables as

regions. For *Region* 3 and sample period S_1, the estimated parameters are identified in 99.97% of all draws from the posterior distribution. In the case of *Region* 4 and the second sample period, the estimated parameters are identified across all draws from the posterior distribution.

5.2 Direct Evidence on Decreasing Real Resource Costs of Transactions

Additional to our estimation results, we provide in this section direct evidence that real transaction costs associated with purchasing consumption goods have declined in the United States. Furthermore, these costs decreased more in the second sample period (1983–2008) than in the first sample period (1964–1979).

One indicator for the fixed costs of transactions is the diffusion of Automated Teller Machines (ATMs) and bank branches. A higher diffusion of ATMs and bank branches indicates smaller fixed costs of transactions for consumers, allowing for more transactions and lower average money holdings. After the installation of the first ATMs in the U.S. at the beginning of the 1970s, their number increased by only 1,755 machines per year from 1973–1979. Between 1983 and 2008, the number of ATMs rose by approximately 13,878 machines per year (Humphrey, 1994, World Bank, 2013).

In Figure 4, we plot the ATM density (bank-branches density), i.e., the number of ATMs (bank branches) per 100,000 adults. The ATM density increased from 1 machine in 1973 to 171 machines per 100,000 adults in 2008. While the annual growth in density amounts to 1 machine between 1973 and 1979, it accelerates to 6 machines from 1983–2008. The density of bank branches increased as well but less than the density of ATMs. This suggests a relative shift from bank branches to ATMs. As emphasized by Barthel (1993), ATMs have a relative cost advantage to bank branches.

Daniels and Murphy (1994) also analyzed the impact of technological change on the demand of money by households. Using cross-sectional survey data for U.S. households on currency and transaction account usage, they found that technological innovations like the increase in ATMs significantly contributed to a decrease in average money holdings in the 1980s.

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the relevant second moments.

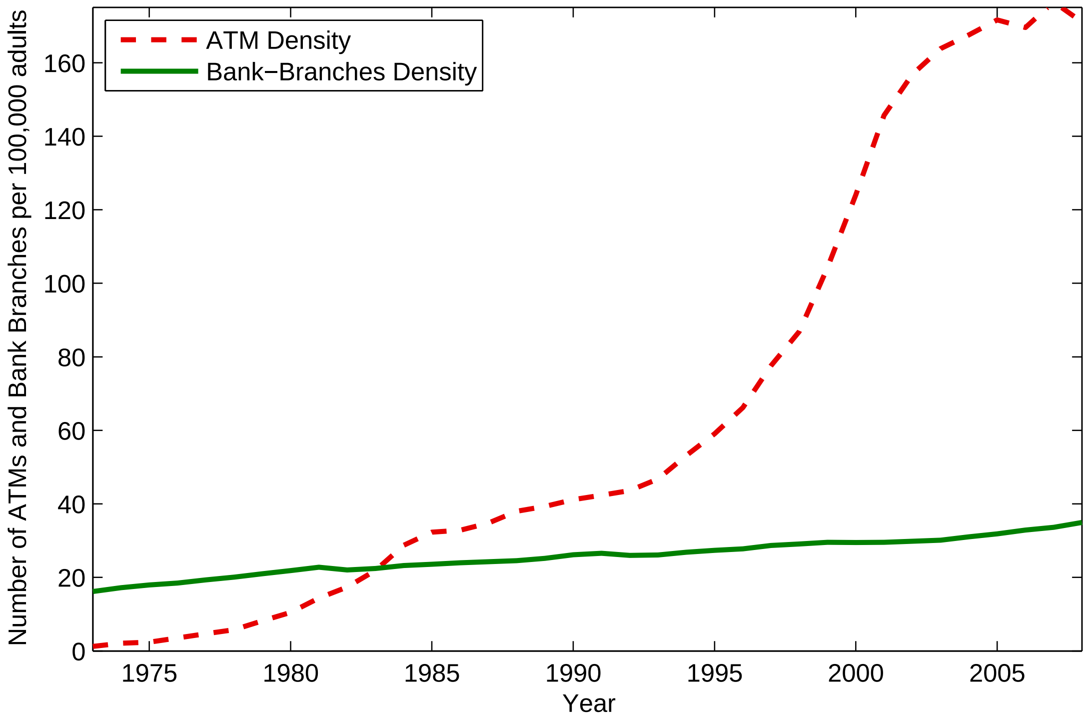

Figure 4: ATM and bank branches per 100,000 adults for the United States between 1973 and 2008. Source: World Bank (ATMs), Federal Deposit Insurance Corporation (FDIC, Branches).

6 Conclusion

We have shown that monetary policy did not destabilize the economy in the pre-Volcker period by following a passive interest rate policy. Instead, the decline in relevance of money in facilitating transactions can explain the well-known fact that U.S. interest rate policy was passive in the pre-Volcker period and active after the disinflation years. To identify the declining role of money as the driving force behind the change in the interest rate policy, we have generalized a standard cashless model by incorporating an explicit transaction role for money. Depending on the importance of money in facilitating transactions, a passive interest rate policy can either lead to a determinate or indeterminate equilibrium. Consistent with the literature, we find that an active interest rate policy ensures equilibrium determinacy after the disinflation years, when money no longer played an important role in facilitating transactions. In the pre-Volcker period, however, money was relevant and determinacy required a passive interest rate policy.

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Appendix

A Proof of Proposition 1

Combining $\widehat{R}_t = \rho_\pi \widehat{\pi}_t$ with (11)–(15) leads to the following characteristic equation:

$$F(x) = x^3 - x^2 \frac{(\kappa+\beta+1)\Upsilon + \omega\kappa\sigma_h}{\beta\Upsilon} + x\frac{\rho_\pi\kappa\omega(\sigma_h - z\eta_{ch}) + (1+\kappa\rho_\pi)\Upsilon}{\beta\Upsilon} + \frac{\omega\kappa\eta_{ch}z\rho_\pi}{\beta\Upsilon} \doteq 0.$$

Normality of consumption and real money balances implies $\Upsilon > 0$. First, $-F(0) = x_1x_2x_3 < 0$ such that there exist either one or three negative roots. Second, $x_1 + x_2 + x_3 = 1 + \kappa/\beta + 1/\beta + (\omega\kappa\sigma_h)/(\beta\Upsilon) > 1$ which excludes the possibility of three negative roots.

Region 1: At least one negative stable root and thus locally unique but oscillatory sequences, arise for $F(-1) < 0$ and $F(1) \geq 0$. The latter condition results in

$$F(1) = (\rho_\pi - 1)\kappa\frac{\Upsilon + \omega\sigma_h}{\beta\Upsilon} \geq 0 \quad \Rightarrow \rho_\pi \geq 1.$$

and prevents the existence of a stable positive root. An negative stable root exists for $F(-1) < 0$

$$\rho_\pi\kappa[2\eta_{ch}z\omega - \Upsilon - \sigma_h\omega] < (2(1+\beta) + \kappa)\Upsilon + \omega\kappa\sigma_h,$$

which is satisfied for $\eta_{ch} \leq \bar{\eta}_{ch}$. For $\eta_{ch} > \bar{\eta}_{ch}$, $\rho_\pi < \bar{\rho}_\pi(\eta_{ch})$ constitutes an additional condition for the existence of one negative stable root.

Region 2: It is $-F(0) < 0$, such that locally indeterminate and stable equilibrium sequences arise when there exist either three negative stable roots (Case 1), or two positive stable roots and one negative unstable root (Case 2), or in Case 3 when there exist one negative stable root as well as one positive stable and one positive unstable root. Case 1 cannot arise because the sum of all roots is positive, Case 2 cannot occur because the sum of all roots is larger than one. The only relevant case is Case 3 which necessarily requires $F(1) < 0$ and thus, $\rho_\pi < 1$. To receive an additional stable but negative root, $F(-1) < 0$ is required which leads to $\rho_\pi < \bar{\rho}_\pi(\eta_{ch})$ if $\eta_{ch} > \bar{\eta}_{ch}$. $F(-1) < 0$ is fulfilled without any additional restriction on the inflation coefficient if $\eta_{ch} \leq \bar{\eta}_{ch}$.

Region 3: Because $F(0) > 0$, locally unique and non-oscillatory equilibrium sequences (exactly one positive stable root) necessarily require $F(1) < 0$ and thus necessarily $\rho_\pi < 1$. To rule out any further stable root in this case, $F(-1)$ must be non-negative, which necessarily results in $\rho_\pi \leq \bar{\rho}_\pi(\eta_{ch})$ if $\eta_{ch} > \bar{\eta}_{ch}$.

B Practical Implementation

We aim at estimating the model when there exists a unique solution as well as when there are indeterminacies. In the latter case, we make use of the method suggested by Lubik and Schorfheide (2003). In the following part, we briefly summarize their method and explain how we implement it.

To solve the model of Section 2, we define the auxiliary variable $\widehat{\zeta}_{x,t-1} = \mathbb{E}_{t-1}\left[\widehat{x}_t\right]$ for a generic variable $\widehat{x}_t$. The corresponding expectation error is thus: $\eta_{x,t} = x_t - \widehat{\zeta}_{x,t-1}$. The number of expectation errors is labeled k_η.

The general form of the model is given by the equation:

$$\Gamma_0 s_t = \Gamma_1 s_{t-1} + \Pi \eta_t + \Psi \epsilon_t, \tag{22}$$

where s denotes the vector of endogenous variables, ϵ the vector of exogenous variables, and η the vector of expectation errors. The vectors are subsequently defined as:

$$s_t = \left[\begin{array}{ccccccccccccccc} \widehat{c}_t & \widehat{y}_t & \widehat{\pi}_t & \widehat{R}_t & \widehat{m}_t & \widehat{w}_t & \widehat{z}_t & \widehat{\nu}_t & \widehat{a}_t & \widehat{g}_t & \widehat{\mu}_t & \widehat{\zeta}_{\nu,t} & \widehat{\zeta}_{z,t} & \widehat{\zeta}_{c,t} & \widehat{\zeta}_{\pi,t} \end{array} \right]',$$

$$\epsilon_t = \left[\begin{array}{cccccc} \epsilon_t^\nu & \epsilon_t^\mu & \epsilon_t^g & \epsilon_t^z & \epsilon_t^a & \epsilon_t^m \end{array} \right]',$$

and

$$\eta_t = \left[\begin{array}{cccc} \eta_{\nu,t} & \eta_{\pi,t} & \eta_{c,t} & \eta_{z,t} \end{array} \right]'.$$

Equation (22) is transformed by first computing the general Schur decomposition of the matrices Γ_0 and Γ_1. We thus solve for the matrices Q, Z, Λ, and Ω such that $Q'\Lambda Z' = \Gamma_0$, $Q'\Omega Z' = \Gamma_1$, $Q'Q = Z'Z = I$. We define the variable $w_t = Z' y_t$, and multiply (22) by Q to derive at the following expression:

$$\begin{bmatrix} \Lambda_{11} & \Lambda_{12} \\ 0 & \Lambda_{22} \end{bmatrix} \begin{bmatrix} w_{1,t} \\ w_{2,t} \end{bmatrix} = \begin{bmatrix} \Omega_{11} & \Omega_{12} \\ 0 & \Lambda_{22} \end{bmatrix} \begin{bmatrix} w_{1,t-1} \\ w_{2,t-1} \end{bmatrix} + \begin{bmatrix} Q_{.1} \\ Q_{.2} \end{bmatrix} (\Pi \eta_t + \Psi \epsilon_t) \,. \tag{23}$$

The upper part of (23) is associated with $w_{1,t}$ and contains the non-explosive eigenvalues of the system. The lower part associated with $w_{2,t}$ contains the explosive eigenvalues. We denote the number of explosive components by m_η. A non-explosive solution to the model (23) exist if $w_{2,0} = 0$, as well as:

$$Q_{.2}\Pi\eta_t + Q_{.2}\Psi\epsilon_t = 0 \tag{24}$$

holds for every ϵ_t. Whether the solution is determinate or indeterminate depends on the $m_\eta \times k_\eta$ matrix $Q_{.2}\Pi$. The singular value decomposition of this expression is given by:

$$Q_{.2}\Pi = \begin{bmatrix} U_{.1} \\ U_{.2} \end{bmatrix} \begin{bmatrix} D_{11} & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} V'_{.1} \\ V'_{.2} \end{bmatrix}$$

The matrix D_{11} is of size $r_\eta \times r_\eta$. The model exhibits a determinate solution if $k_\eta = r_\eta$, and an indeterminate solution if $k_\eta > r_\eta$. In the former case, (24) can be used to solve for η_t as a function of ϵ_t. This solution is inserted into (23) and the recursive law of motion for s_t is given by:

$$s_t = \Gamma_1^\star s_{t-1} + \left(\Psi^\star - \Pi^\star V_{.1} D_{11}^{-1} U'_{.1} Q_{.2}\Psi\right)\epsilon_t, \tag{25}$$

where $\Gamma_1^\star = Z \begin{bmatrix} \Lambda_{.1}^{-1}\Omega_{.1} \\ 0 \end{bmatrix} Z'$, $\Psi^\star = Z \begin{bmatrix} \Lambda_{.1}^{-1} \\ 0 \end{bmatrix} Q\Psi$, and $\Pi^\star = Z \begin{bmatrix} \Lambda_{.1}^{-1} \\ 0 \end{bmatrix} Q\Pi$. $\Lambda_{.1}$ and $\Omega_{.1}$ represent the parts of the matrices Λ and Ω associated with the stable eigenvalues. In the case of $k_\eta > r_\eta$, the solution is to the model is indeterminate and the matrix $V_{.2}$ is non-empty. In this case, Lubik and Schorfheide (2003) show that there exists a modified solution for ϵ_t in dependence of η_t. The modified recursive law of motion for s_t is given by:

$$\begin{aligned} s_t &= \Gamma_1^\star s_{t-1} + \left(\Psi^\star - \Pi^\star V_{.1} D_{11}^{-1} U'_{.1} Q_{.2}\Psi\right)\epsilon_t \\ &\quad + \Pi^\star \left(V_{.2} M_1 \epsilon_t + V_{.2} M_2 \tilde{\epsilon}_t\right), \end{aligned} \tag{26}$$

where $\tilde{\epsilon}_t$ denotes an additional error term, the sunspot shock. M_1 and M_2 denote matrices, which we determine following Lubik and Schorfheide (2004). The matrix M_2 is set to unity and the standard deviation of the sunspot shock $\tilde{\epsilon}$ is estimated as an additional parameter. The matrix M_1 is split up into two matrices: $M_1 = M_{11} + M_{12}$. The matrix M_{11} is chosen such that the impulse response functions of s to ϵ are continuous at the boundary between the determinate regions and the indeterminate regions. More precisely, consider a parameter vector from an indeterminacy region (θ^I). The corresponding parameter vector (θ^D) that lies on boundary is obtained by replacing the value ρ_π in θ^I. According to Proposition 1, the particular value of ρ_π depends on the value of η_{ch}. If $0 \leq \eta_{ch} \leq \bar{\eta}_{ch}$, ρ_π is set to $\rho_\pi = 1$. If $\eta_{ch} > \bar{\eta}_{ch}$ holds, ρ_π is set to $\bar{\rho}_\pi(\eta_{ch})$.

We re-write the impulse response function $\frac{\partial s_t}{\partial \epsilon_t}$ corresponding to (26) as $\frac{\partial s_t}{\partial \epsilon_t}(\theta, M_1) = B_1(\theta) + B_2(\theta, M)$, where B_1 and B_2 are defined as

$$B_1 = \left(\Psi^\star - \Pi^\star V_{.1} D_{11}^{-1} U_{.1}' Q_{.2} \Psi\right)$$

and

$$B_2 = \Pi^\star V_{.2}.$$

In the case of determinacy the impulse response function consists solely of B_1, in the case of indeterminacy it is the sum of B_1 and B_2. M_{11} is chosen to minimize the difference the impulse response functions associated with θ^I and θ^D respectively. The condition for M_{11} is given by :

$$M_{11}^\star = \left[B_2(\theta^I)' B_2(\theta^I)\right]^{-1} \times B_2 \theta^{I'} [B_1(\theta^D) - B_1(\theta^I)]. \tag{27}$$

Finally, the entries of the matrix M_{12} are either estimated employing a prior distribution centered around zero or set equal to zero. In our indeterminacy specification we start by setting the entries of M_{12} as well as the standard deviation of the sunspot shock equal to zero.[13] We have subsequently relaxed these assumptions and included the corresponding parameters into the estimation. The main results, i.e. the order of importance of the different regions, have not been affected.

To summarize this section, we repeat our steps to solve the DSGE model. For every parameter vector θ, we check whether a non-explosive solution exists. Afterwards we examine whether the solution is determinate or indeterminate. In the former case, we compute the recursive laws of motion using (25). In the latter case, we employ (26) to solve for the recursive laws of motion.

[13] Note that even if there is no sunspot shock present, indeterminacy still renders the recursive laws of motion of s_t through the changed impact of the exogenous disturbance.

The matrix matrix M_2 is set equal to zero, the matrix M_1 is determined by (27).

C Data Appendix

The frequency of all data used is quarterly. The data has been obtained in September 2011.

Real GDP: This series is *BEA NIPA table 1.1.6 line 1.*

Nominal GDP: This series is: *BEA NIPA table 1.1.5 line 1.*

Implicit GDP Deflator: The implicit GDP deflator is calculated as the ratio of Nominal GDP to Real GDP.

Civilian noninstitutional population: This series is taken from:
http://research.stlouisfed.org/fred2/series/CNP16OV?cid=104.

Nominal hourly wages total private industry: This series is $AHETPI$ obtained from Fred:
http://research.stlouisfed.org/fred2/series/ahetpi/10.

Interest rates: This series is the effective federal funds rate obtained from Fred:
http://research.stlouisfed.org/fred2/series/FEDFUNDS.

Money balances M2: This series is M2 obtained from Fred:
http://research.stlouisfed.org/fred2/series/M2.

Money balances M1: This series is M1 obtained from Fred:
http://research.stlouisfed.org/fred2/series/M1SL?cid=25.

D Tables and Figures

Table 3: Prior distributions for model parameters

Parameter	distribution	mean	std
$\rho_{\pi,\mathcal{R}1,\mathcal{R}4}$	normal	1.5	0.2
$\rho_{\pi,\mathcal{R}2,\mathcal{R}3,\mathcal{R}5}$	beta	0.85	0.1
ρ_R	beta	0.8	0.1
ρ_y	gamma	0.5	0.1
γ	beta	0.5	0.1
α	beta	0.5	0.1
δ	beta	0.5	0.1
$\eta_{ch,\mathcal{R}1}$	gamma	0.07	0.025
$\eta_{ch,\mathcal{R}2}$	gamma	0.1	0.05
$\eta_{ch,\mathcal{R}3}$	gamma	0.3	0.1
σ_{h,S_1}	gamma	3.5	0.5
η_{hc,S_1}	gamma	2.8	0.5
σ_{h,S_2}	gamma	3.9	0.5
η_{hc,S_2}	gamma	3.12	0.5
ρ_g	beta	0.5	0.2
ρ_a	beta	0.5	0.2
ρ_μ	beta	0.5	0.2
ρ_z	beta	0.5	0.2
ρ_ν	beta	0.5	0.2
σ_g	invgamma	0.04	inf
σ_a	invgamma	0.04	inf
σ_μ	invgamma	0.04	inf
σ_z	invgamma	0.04	inf
σ_ν	invgamma	0.04	inf
σ_m	invgamma	0.04	inf

Table 4: Posterior probabilities of regions for Pre-Volcker and Post-1982

	$\mathcal{R}1$	$\mathcal{R}2$	$\mathcal{R}3$	$\mathcal{R}4$	$\mathcal{R}5$
1. Pre-Volcker					
Log marginal data density, $\log \tilde{p}_{\mathcal{R}_i}(Y_{T,1})$	729.20	671.31	737.57	733.87	705.28
Probability, $\pi_{\mathcal{R}i}$	0.00	0.00	0.98	0.02	0.00
2. Post-1982					
Log marginal data density, $\log \tilde{p}_{\mathcal{R}_i}(Y_{T,1})$	1607.70	1559.80	1581.44	1609.23	1588.43
Probability, $\pi_{\mathcal{R}i}$	0.18	0.00	0.00	0.82	0.00

E Robustness

In this subsection, we conduct five robustness exercises. The purpose of this section is to check if the change in the most likely region – from a determinate monetary region with passive interest rate policy to a determinate cashless region with active interest rate policy – prevails for numerous changes in the specification. For the purpose of the section, it is convenient to define the following relative probability of *Region* 3

$$\tilde{\pi}_{\mathcal{R}3} = \frac{\tilde{p}_{\mathcal{R}i}(Y_{T,1})}{\tilde{p}_{\mathcal{R}3}(Y_{T,1}) + \tilde{p}_{\mathcal{R}4}(Y_{T,1})}.$$

Correspondingly, the probability of *Region* 4 amounts to $\tilde{\pi}_{\mathcal{R}4} = 1 - \tilde{\pi}_{\mathcal{R}3}$. We start by considering transaction costs that are of first order, i.e., they appear as part of the right-hand side in the aggregate resource constraint (14). As a second exercise, we employ a specification with persistent monetary policy shocks. Next, we use real money balances based on M1 instead of M2 as an observable variable. Furthermore, we apply a different filter to the observable variables, and also extend the set of cashless equilibrium sequences with various endogenous propagation features.

First-order transaction costs We now analyze the implications of first-order transaction costs, such that the log-linearized version of the aggregate resource constraint now reads:

$$\widehat{y}_t = \left(1 - \frac{g}{y} - \frac{\phi}{y} + \eta_c\right)\widehat{c}_t + \widehat{g}_t - \eta_h(\widehat{m}_{t-1} - \widehat{\pi}_t + \widehat{z}_t), \tag{28}$$

where the two new parameters are $\eta_c \equiv \phi_c c/\phi$ and $\eta_h \equiv -\phi_h h/\phi$; ϕ/y are steady-state transaction costs relative to output. We estimate *Region* 3 with these two new parameters using for both a Gamma distribution with mean of 0.05 and standard deviation of 0.03 as prior distribution. The estimation results are displayed in Table 5.

The log marginal data density of *Region* 3 with transaction costs in the aggregate resource constraint increases relative to the baseline specification in Table 1 in the first subsample (742.38 vs. 737.57). Thus, the region associated with the highest posterior probability continues to be the determinate monetary region. As in the baseline estimation, the marginal data density of *Region* 3 with transaction costs of first order in the second subsample is lower than the marginal data density of *Region* 4. This confirms our main result on the link between the

Table 5: Monetary versus Cashless Region (II)

	Pre-Volcker		Post-1982	
	$\mathcal{R}3$	$\mathcal{R}4$	$\mathcal{R}3$	$\mathcal{R}4$
Log marginal data density, $\tilde{p}_{\mathcal{R}i}(Y_{T,1})$	742.38	732.12	1585.80	1609.23
Probability, $\tilde{\pi}_{\mathcal{R}i}$	1.00	0.00	0.00	1.00

Notes: Log marginal data densities and posterior model probabilities for the monetary *Region* 3 with transaction costs of first-order and for the cashless *Region* 4.

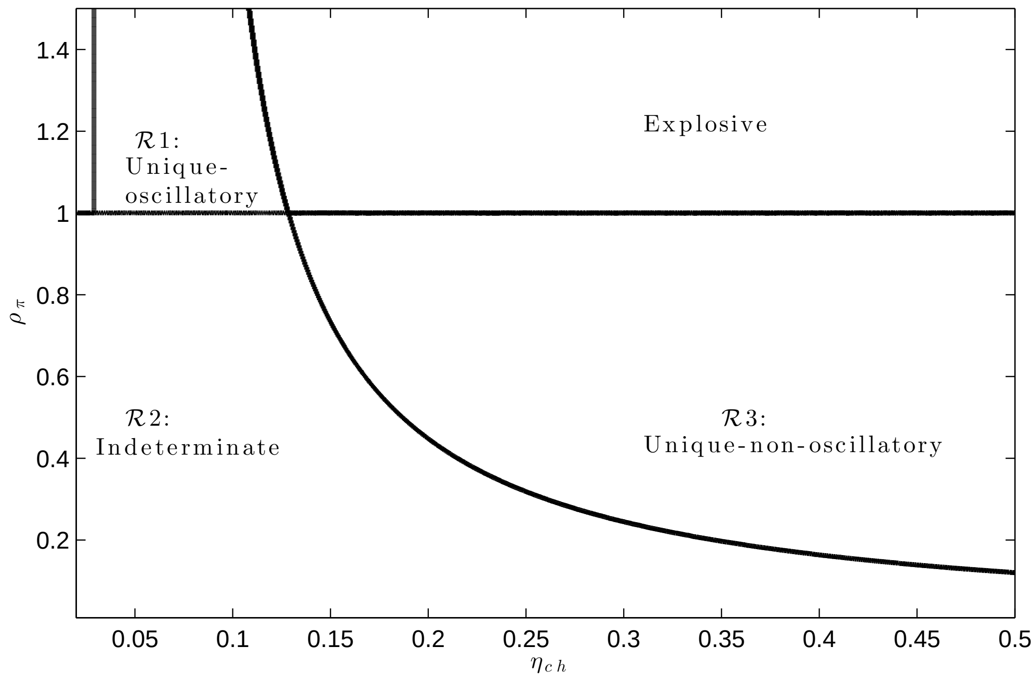

Figure 5: Stability and uniqueness of equilibrium sequences for $\eta_{ch} > 0$ and first-order transaction costs.

declining importance of money in transactions and the switch in interest rate policy. The non-oscillatory monetary region is the most likely region in the pre-Volcker period, while after the disinflation years the cashless economy is most likely.

First-order transaction costs may affect the partition of the regions of equilibrium sequences as displayed in Figure 2 in the main text. To check this, we employ the specification of the aggregate resource constraint (28), and fix the parameter values (except for η_{ch} and ρ_π) to their posterior mean as estimated for *Region* 3 in the Pre-Volcker era.[14] As displayed in Figure 5, the regions look very similar to the regions that occur when transaction costs are zero to first order.

[14] The posterior means for the new parameters η_h and η_c are 0.0284 and 0.2649 respectively. The fraction of steady-state transaction costs are three percent of steady-state output.

Table 6: Monetary versus Cashless Region (III)

	Pre-Volcker		Post-1982	
	$\mathcal{R}3$	$\mathcal{R}4$	$\mathcal{R}3$	$\mathcal{R}4$
Log marginal data density, $\tilde{p}_{\mathcal{R}i}(Y_{T,1})$	746.67	738.03	1607.09	1622.37
Probability, $\tilde{\pi}_{\mathcal{R}i}$	1.00	0.00	0.00	1.00

Notes: Log marginal data densities and posterior model probabilities for the monetary *Region* 3 and for the cashless *Region* 4 estimated with an autoregressive monetary policy shock.

To the left of *Region* 1, there is now a small region which also features unique non-oscillatory equilibrium sequences. However, when we estimate this region with a prior centered in it, we find that the new region has a posterior probability of zero in both sample periods.

Persistent monetary policy shocks As an alternative interest rate rule, we specify an autocorrelated monetary policy shock term. More precisely, the error term r_t^m in (4) is now assumed to follow the process:

$$\log r_t^m = \rho_m \log r_{t-1}^m + \epsilon_t^m.$$

We specify the prior distribution for the additional parameter ρ_m similar to the other autoregressive parameter as a beta distribution with a mean of 0.5 and a standard deviation of 0.2. As the results in Table 6 show, the marginal data density for both regions of interest $\mathcal{R}4$ and $\mathcal{R}3$ increases. The posterior probability before Volcker is still in favor of *Region* 3, while after the disinflation years *Region* 4 exhibits the highest posterior probability. Thus, the results found in the baseline estimation are robust with respect to the specification of an alternative interest rate rule.

Real money based on M1 as an observable As a second robustness exercise, we use real money balances based on the more narrow monetary aggregate M1 as an observable variable. Compared to M2, M1 does neither comprise saving deposits nor time deposits nor individual money-market deposits. As displayed in Table 7, the equilibrium sequences associated with a transaction role of money and a passive interest rate policy in *Region* 3 continue to exhibit the highest posterior probability in the pre-Volker era. Also as in our baseline estimation, the cashless *Region* 4 prevails as the most likely region after the disinflation years with an active

Table 7: Monetary versus Cashless Region (IV)

	Pre-Volcker		Post-1982	
	$\mathcal{R}3$	$\mathcal{R}4$	$\mathcal{R}3$	$\mathcal{R}4$
Log marginal data density, $\tilde{p}_{\mathcal{R}i}(Y_{T,1})$	754.47	731.73	1563.31	1606.09
Probability, $\tilde{\pi}_{\mathcal{R}i}$	1.00	0.00	0.00	1.00

Notes: Log marginal data densities and posterior model probabilities for the monetary *Region* 3 and for the cashless *Region* 4 as the most likely regions for real money based on M1 as an observable variable.

Table 8: Monetary versus Cashless Region (V)

	Pre-Volcker		Post-1982	
	$\mathcal{R}3$	$\mathcal{R}4$	$\mathcal{R}3$	$\mathcal{R}4$
Log marginal data density, $\tilde{p}_{\mathcal{R}i}(Y_{T,1})$	665.05	652.77	1505.94	1527.37
Probability, $\tilde{\pi}_{\mathcal{R}i}$	1.00	0.00	0.00	1.00

Notes: Log marginal data densities and posterior model probabilities for the monetary *Region* 3 and for the cashless *Region* 4 as the most likely regions when observable variables are de-trended with a one-sided HP filter.

interest rate setting.

Removing the trend with a one-sided HP filter In Table 8, we provide the model probabilities when real output, real consumption, real wages and real money balances (based on M2) are de-trended with a one-sided HP filter. The estimation results confirm our earlier findings. The log-data densities are smaller than the corresponding expressions in Tables 1 and 7. The reason for this difference is that the initiation of the one-sided HP filter results in a reduction of the total number of data points available for estimation.

Endogenous propagation in the standard cashless economy Our estimation results in Table 1 state that the local dynamics in the monetary *Region* 3 better describe the data in the pre-Volcker era than the purely forward-looking cashless economy from *Region* 4. This finding is independent of the particular monetary aggregate observed – M1 or M2 – and also does not depend on the linear-quadratic de-trending employed in our baseline estimation or on the assumption of a non-persistent monetary policy shock. One reason for the finding, however, might be that the equilibrium sequences in the cashless region miss an endogenous state variable in the propagation of shocks. To test this hypothesis, we extend the cashless *Regions* 4 with an external habit in consumption with parameter $0 \leq \gamma \leq 1$ and allow for partial indexation to the past inflation rate with parameter $0 \leq \delta \leq 1$. For an external habit, $u(c_{jt} - \gamma c_{t-1}, \nu_t)$, the equilibrium marginal utility of consumption in period t in log-linearized terms reads

$$-\sigma_c \widehat{c}_t + \gamma \sigma_c \widehat{c}_{t-1} + \nu_t.$$

Firms that are not allowed to adjust prices in period t can partially index their prices to the past inflation rate, that is, they set $\log P_{it} = \log P_{it-1} + \delta \log \pi_{t-1}$. The Phillips curve (13) is therefore replaced by the following expression

$$\widehat{\pi}_t(1 + \beta\delta) = \beta\, \mathbb{E}_t\, \widehat{\pi}_{t+1} + \delta \widehat{\pi}_{t-1} + \frac{(1-\alpha)(1-\alpha\beta)}{\alpha}(\widehat{w}_t - \widehat{a}_t).$$

In a recent paper, Coibion and Gorodnichenko (2011) argued that the Federal Reserve Bank was responding to the output gap and the expected output growth. Following their suggestion, we replace the interest rate feedback rule (16) with the following alternative specification

$$\widehat{R}_t = (1 - \rho_R)\left[\rho_\pi \widehat{\pi}_t + \rho_x x_t + \rho_{gy}\left(\mathbb{E}_t\, \widehat{y}_{t+1} - \widehat{y}_t\right)\right] + \rho_R \widehat{R}_{t-1} + \varepsilon_t^m,$$

where $\rho_R \geq 0$ is an interest rate smoothing parameter, and $\rho_x \geq 0$ captures an endogenous response on the current output gap, $\widehat{y}_t - \widehat{y}_t^n$, and $\rho_{gy} \geq 0$ denotes the response to expected output growth. The natural rate of output, $\widehat{y}_t^n$, is the backward solution of the following difference equation

$$(\omega + \tilde{\sigma}_y)\, \widehat{y}_t^n - \frac{\sigma_c \gamma}{s_C} \widehat{y}_{t-1}^n = (1+\omega)\widehat{a}_t + \widehat{\nu}_t - \widehat{\mu}_t + \tilde{\sigma}_y \widehat{g}_t - \frac{\sigma_c \gamma}{s_C} \widehat{g}_{t-1}.$$

In this robustness exercise, only the cashless economy is extended with the features mentioned, the equilibrium sequences in the monetary *Region* 3 are unchanged. The corresponding estimation results – employing again the linear quadratic de-trending method from the baseline estimation and $M2$ – are reported in Table 9 and confirm once more our findings on the decreasing role of money.

Table 9: Monetary versus Cashless Region (VI)

	Pre-Volcker		Post-1982	
	$\mathcal{R}3$	Extended $\mathcal{R}4$	$\mathcal{R}3$	Extended $\mathcal{R}4$
Log marginal data density, $\tilde{p}_{\mathcal{R}i}(Y_{T,1})$	737.57	733.05	1581.44	1608.34
Probability, $\tilde{\pi}_{\mathcal{R}i}$	0.99	0.01	0.00	1.00

Notes: Log marginal data densities and posterior model probabilities for an extended cashless economy and for *Region* 3 as the most likely regions. Linear quadratic de-trending and real money balances based on $M2$.