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Inflation Targeting and the Role of Money in a Model with Sticky Prices and Sticky Money

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Abstract

In order to study the role of money in an inflation targeting regime for monetary policy, we compare the interest rate and money as monetary policy instruments. Our dynamic stochastic general equilibrium model combines the money-in-the-utility-function approach with sticky prices. We allow for time-varying preferences for real money balances, ie velocity shocks, and stochastic aggregate costs in production, ie 'technology shocks'. We show that conditioning the interest rate on the expected future cost change can be used to achieve constant inflation or constant inflation expectations. The assumed adjustment costs in 'money demand' lead to an equilibrium in which inflation can be controlled by money growth without information on the current state of the economy. Finally, we discuss the tradeoff between money and the interest rate as a monetary policy instrument. The result depends on the parameter stability of the cost change process relative to that of the 'money demand' function.

Keywords: monetary transmission mechanism, money-in-the-utility-function model, sticky prices, technology shock, monetary policy strategy

JEL classification: E31, E41, E52

Tiivistelmä

Tutkimuksessa selvitetään rahan roolia, kun rahapolitiikalla on suora inflaatiotavoite. Lisäksi vertaillaan rahan määrää ja korkoja rahapolitiikan ohjausvälineinä. Tarkastelukehikkona on dynaamisen raha hyötyfunktiossa-mallin muunnelma, jota on täydennetty yrityssektorin epätäydelliseen kilpailuun perustuvilla hintajäykkyyksillä. Teknisen kehityksen ja rahan tuottamien likviditeettipalvelusten vaihtelun oletetaan olevan talouden dynamiikan taustalla. Tutkimuksessa osoitetaan, että sekä inflaatio että inflaatio-odotukset voidaan vakauttaa ehdollistamalla korkopäätökset odotetulle teknisen kehityksen kasvuvauhdille. Lisäksi osoitetaan, että rahan määrän sopeutumiskustannusten vuoksi inflaatio voidaan vakauttaa myös rahan määrää hallinnoimalla ja vielä ilman tietoa talouden tämänhetkisistä häiriöistä. Siihen, kannattaako rahapolitiikan ohjausvälineenä käyttää rahan määrää vai korkoja, vaikuttaa keskeisesti se, osataanko tuleva tekninen kehitys arvioida riittävän tarkasti ja tunnetaanko rahan kysyntään liittyvät mallin parametrit.

Asiasanat: rahapolitiikan välittymismekanismi, raha hyötyfunktiossa -malli, hintajäykkyys, tekninen kehitys, rahapolitiikan strategia

JEL luokitus: E31, E41, E52

Contents

1 Introduction

Central banks have increasingly argued that only prices are under their control in the long run. Consequently, they should be responsible for price stability, ie they should set their policy instrument so as to target the price level or inflation. There are, of course, nuances concerning how to implement such a target. A number of countries, eg New Zealand, the United States, Canada and more recently the United Kingdom, Sweden, Finland, Spain and Ireland, have specified inflation as the direct target of their policies. However, the German Bundesbank still uses monetary aggregate as an intermediate target while aiming at price stability.

More recently (see eg EMI 1997) it has been discussed whether the forthcoming European System of Central Banks (ESCB) should conduct direct inflation targeting or monetary targeting. Without using any explicit model, EMI (1997) argues that both are based on the same final objective (price stability), both are forward looking, and both employ a wide range of indicators.

The purpose of this study is to analyse inflation targeting with a fully articulated model. The model should permit us to discuss the choice of the monetary policy instrument and the information requirements of instruments and the instrument rules.

EMI (1997) defines inflation targeting as a monetary policy strategy whereby the central bank uses an interest rate instrument to directly control inflation, ie the approach applied by the countries mentioned above. Monetary targeting is defined as the Bundesbank approach whereby money serves as an intermediate target; inflation is the ultimate goal of monetary policy and interest rates are used as an instrument. In this study we use the same definition of inflation targeting but we assume that the money stock can be set at exactly the desired level. Then money stock could be called an instrument rather than an intermediate target.

An instrument is a tool that central bank can directly control. There are no control errors; the instrument variable can for all practical purposes be set exactly. Examples are the monetary base and the discount rate. When an instrument can be set precisely and there is no uncertainty in the model or in the parameters, no instrument choice problem exists. The target can be achieved precisely with any instrument. However, when the model incorporates uncertainty, we face the problem of ordering uncertainty and actions. If deviations from the target are possible, the uncertainty must occur *after* the instrument is set. Otherwise the target again can be fully controlled.

We investigate the instrument rules. Instrument rules are instrument settings that are conditional on the state of the economy and that lead to either constant inflation or constant inflation expectations. The instrument choices under consideration are the interest rate and money. Since Poole (1970), there has been a long tradition of studying the optimal choice of a monetary policy instrument. We evaluate the instruments with respect to their ability to meet the inflation or inflation expectations target and with respect to their requirement concerning information on the structure of economy.

Inflation targeting means that central bank either wants to restrict inflation or inflation expectations to a certain targeted level. Svensson (1996) calls the latter case inflation forecast targeting. The difference between these two approaches lies in the information setup: if the central bank observes the current period shocks to the economy, it can control the inflation. However, if it has to move first, ie determine the value of an instrument before the shocks hit, it can fix only the expected inflation rate.

Despite the short-term nonneutrality of monetary policy in our model, we analyse monetary policy only in the case where the central bank is able to commit to the announced policy. Consequently, using the terminology of Svensson (1997), we study the case of strict inflation targeting.

The model at hand describes the dynamics between money, interest rates and inflation. We use the log-linearized version of the money-in-the-utility-function (MIUF) model augmented with adjustment costs, as in Ripatti (1997), to derive the dynamic relationship between money, prices, consumption and interest rates. Firms' behaviour is modelled as in Rotemberg (1981, 1982), where the monopolistic firm faces costs (eg menu costs) when it changes the price of its product. The demand function faced by the monopolistic firm is based on a constant elasticity of substitution of goods. Our approach is to combine the adjustment cost-augmented MIUF and Rotemberg's sticky price model and augment them with stochastic preferences for money and stochastic aggregate cost (technology) shocks. The model is analysed in section 2.

Our choice for introducing money into the economy is the money-in-the-utility-function approach. This approach is also applied by Obstfeld and Rogoff (1995), Hairault and Portier (1993) and Blanchard and Kiyotaki (1987). Another motivation for the existence money is to introduce the cash-in-advance constraint. This was done by Carlstrom and Fuerst (1995), Rotemberg (1987), Svensson (1986), Yun (1996), Baba (1997) and Obstfeld and Rogoff (1996). A third route was chosen by King and Wolman (1996), who follow McCallum and Goodfriend (1987) by assuming that money shortens shopping time. Money simplifies transactions in the model by Reinhart (1992). Our system is designed to capture the persistence of money growth by introducing costs in the adjustment of money holdings. Carlstrom and Fuerst (1995) augment their model with the constraint that part of the household's cash is to be deposited into a financial intermediary, which is also a type of adjustment cost.

Price rigidity is introduced into our model via menu (adjustment) costs as suggested by Rotemberg (1982). Other alternatives, which show up in real business cycles models with price rigidities, include staggered price changes (Calvo 1983) and prefixed prices (eg Svensson 1986). As Rotemberg (1987) notes, the first two choices are observationally equivalent. Price adjustment *à la* Rotemberg (1982) is also used by Baba (1997) and Rotemberg (1987). Hairault and Portier (1993), which follows the MIUF approach, also includes quadratic price adjustment costs, while differing in detail from Rotemberg (1981). Even though the quadratic adjustment cost approach is easily critized (see footnote 7), it is a very simple modelling device and has the advantage of yielding log-linear approximation. Another alternative for a price adjustment mechanism would be based on the model by Calvo (1983), where price changes are geometrically (discrete case) or exponentially (continuous case) distributed. This has been used by Yun (1996), Rotemberg and Woodford (1997), Reinhart (1992), Kollmann (1997) and King and Wolman (1996). Svensson (1986) assumes that goods prices are predetermined, ie that they adjust only to the lagged state of the market. To simplify their models, Obstfeld and Rogoff (1995), Obstfeld and Rogoff (1996) and Rotemberg and Woodford (1997) assume that the representative household is both consumer and producer and thus include production in the utility function. This of course simplifies the welfare analysis. They do not need to assume any price rigidities in their models and yet demand has short-run effects. The seminal paper by Blanchard and Kiyotaki (1987) has uses a static approach and relies on the assumption of incomplete markets, which has also been critized (see eg Carlton 1996).

We also introduce two kinds of driving forces into our model. The first one, labelled velocity shock, captures the representative household's stochastic preferences for real money balances. It also allows for velocity shocks that are independent of interest rates. We study how changes in preferences for holding money, ie for the liquidity services produced by money, influence computed equilibrium. In the spirit of RBC models, we also introduce a (inverted) technology shock into the cost function of the representative monopolist, calling it a cost shock.

As noted at the end of section 2, it turns out that we are able to characterize the equilibrium relationship between inflation and expected interest rates without knowledge of 'money demand' parameters and velocity shocks. This corresponds to the situation where the central bank has a direct inflation target and uses interest rates as its monetary policy instrument. In such a setup, money is recursively determined by expected exogenous shocks and interest rates.

We study the feasible interest rate paths, ie the interest rate paths that yield finite inflation, in section 3. This gives us a kind of benchmark equilibrium. We continue by studying more ambitious monetary policies. We cover the cases where the central bank targets either inflation or inflation expectations. As a sufficient condition, we propose two interest rate rules where the interest rate is conditioned on the expected future cost change. These rules are compared to the classical rule whereby the interest rate is conditioned on current inflation. The main lessons from this exercise is that inflation cannot be stabilized without considering cost-change expectations.

A novel feature of our model is that we are able to ascribe a role to money. The role arises from the adjustment costs. Due to the adjustment costs, money growth captures the expectations for future interest rates and cost changes. We get an equilibrium in which money is the only *current* determinant of inflation. Consequently we are able to propose a money rule, where money is conditioned on period $t-1$ state variables, ie variables that the central bank can observe. In order to utilize this framework the central bank must know more of the parameters of the model.

Finally, in the last section, we discuss the choice of monetary policy strategy, which in our case is the choice of a monetary policy instrument. We conclude that it is a highly empirical question whether money or an interest rate should be used as a monetary policy instrument.

2 A Model with Sticky Money and Sticky Prices

Although Lucas (1988) prefers to base the 'money demand model', or rather the relationship between money, consumption and interest rates, on the cash-in-advance constraint, we have chosen to include real balances directly in the utility function. Other options modelling the demand for money would be transactions costs and shopping time models. However, the money-in-the-utility-function (MIUF) has the advantage of analytical simplicity and it allows us to illustrate the dynamics of the relationship.

The strong persistence[1] of nominal balances and its growth rate suggests that changes in nominal balances involve adjustment costs. Consequently, we augment the usual MIUF model with adjustment costs for changing money holdings. Adjustment costs for changing money holdings is somewhat artificial since money should be the asset that is most cheaply exchanged. On the other hand, one can imagine that there are costs involved in adjusting eg bank accounts[2], ie shoe sole costs. However, we believe that adjustment costs comprise an approximate modelling device for incorporating dynamics in 'money demand' analysis. On the aggregate level they could, for example, mimic more complex dynamics, eg (s, S) behaviour. The MIUF model is derived in section 2.1.

The motivation of modelling prices as sticky also relates to the empirical argument that inflation seems to be so persistent that it could even be approximated by an integrated processes. In addition to price stickiness, we assume monopolistic competition, in order to introduce demand effects into our model. The Euler equation expressing the model's supply characteristics is introduced in section 2.3.

Since the purpose of the model is to analyze the choice of monetary policy and to estimate the model parameters, we linearize the model[3]. We mainly utilize the first order Taylor approximation around the — hopefully cointegrated and thus stationary — steady state. The loglinearization is separated in section 2.2. Although the model is not entirely classical, its steady state properties are very classical. The steady state is examined in section 2.4. Section 2.5 discusses possible equilibria and we leave most of the monetary policy issues to section 3.

2.1 Household Preferences

The economy is inhabited by infinitely lived households, firms and the monetary authority (central bank). It also includes a continuum of differentiated goods that are produced by monopolistically competitive firms. The firms and goods are indexed by $z \in [0, 1]$. The differentiated goods are aggregated to produce a single composite good, which yields utility to the household.

[1]See the extensive literature on demand for money studies based on cointegration techniques.

[2]Bank accounts are usually at least partly incorporated in money measures.

[3]The estimation and testing theory for models with (possibly) nonstationary variables is fairly well established for linear models.

The *household* optimizes the discounted sum of expected utility from consumption and real money balances:

$$\max E_0 \sum_{t=0}^{\infty} \delta^t \left[u(C_t) + \mathfrak{Z}_t v\left(\frac{M_t}{P_t}\right)\right].$$

The household allocates its 'phantom' income y (ie periodic exogenous endowment) and other earnings among (composite) consumption (C_t: real value of consumption), bonds (B_t: real value of bonds denominated in units of time t consumption) which pay a gross real return of $1 + r_t$ (from time t to time $t + 1$), and real money balances, $\frac{M_t}{P_t}$, which pay a gross return $\frac{P_{t+1}}{P_t}$. Whenever it adjusts its money balances between period $t-1$ and period t, the household suffers losses amounting in real terms to $a(M_t, M_{t-1}, M_{t-2})/P_t$. The household's budget constraint is

$$C_t + B_t + \frac{M_t}{P_t} + \frac{a(M_t, M_{t-1}, M_{t-2})}{P_t} \leq y + \frac{M_{t-1}}{P_t} + (1 + r_{t-1})B_{t-1}. \tag{1}$$

We also assume that the period utility obtained from consuption and real money balances are concave, ie $u'(\cdot) > 0$, $u''(\cdot) < 0$, $v'(\cdot) > 0$ and $v''(\cdot) < 0$.

C_t is the number of units of the composite good available at period t:

$$C_t = \left[\int_0^1 C_t(z)^{\frac{\theta-1}{\theta}} dz\right]^{\frac{\theta}{\theta-1}}, \tag{2}$$

where $\theta > 1$ is the constant elasticity of substitution (CES). The price deflator for nominal money balances is the consumption-based money price index implicit in (2). It is obtained as a solution of the cost minimization problem subject to the aggregator (2):

$$P_t = \left[\int_0^1 P_t(z)^{1-\theta} dz\right]^{\frac{1}{1-\theta}}. \tag{3}$$

Note that the utility function is additive and the weight of utility gained by the representative household from the real money balances is stochastic. Since we utilize the representative household approach it is quite natural to allow real money balances to yield stochastic liquidity services. Consequently, the stochastic variable $\mathfrak{Z}_t$ is introduced to allow for stochastic transaction technology. Another way of interpretating this is that the velocity shock allows for changes of time in the heterogeneity of households. Stochastic preferences for liquidity services yielded by money can be motivated so as to allow for shocks to money demand — or to velocity — that are independent of monetary policy. Hence, velocity cannot be controlled via monetary policy.

When we iterate the budget constraint, we obtain the following transversality condition:

$$\lim_{T\to\infty} E_t \prod_{j=0}^{T} \frac{1}{1 + r_{t+j}} \left(B_{t+1+T} + \frac{M_{t+1+T}}{P_{t+1+T}}\right) = 0. \tag{4}$$

This states that the present value of financial assets held in period T (real bonds and money) tends to zero as time T tends to infinity. That is to say the financial assets' expected growth is restricted to be below the real rate, r.

The first-order conditions for bonds and real money balances are

$$\delta E_t\{(1+r_t)u'(C_{t+1})\} = u'(C_t) \tag{5}$$

$$1+a'_{M_t}(M_t, M_{t-1}, M_{t-2}) = \delta E_t\left\{\frac{P_t}{P_{t+1}}\frac{u'(C_{t+1})}{u'(C_t)}\left[1-a'_{M_t}(M_{t+1}, M_t, M_{t-1})\right]\right\} + \mathfrak{z}_t\frac{v'\left(\frac{M_t}{P_t}\right)}{u'(C_t)}. \tag{6}$$

We assume that a nominal bond exists in our economy. The condition (5) for the nominal bond is given by

$$(1+i_t)\delta E_t\left\{\frac{1}{P_{t+1}}u'(C_{t+1})\right\} = \frac{1}{P_t}u'(C_t). \tag{7}$$

If we combine the additional assumption that

$$\mathrm{cov}_t\left(\frac{P_t}{P_{t+1}}\frac{u'(C_{t+1})}{u'(C_t)}, \left[1-a'_{M_t}(M_{t+1}, M_t, M_{t-1})\right]\right) = 0 \tag{8}$$

with the equation (7), the condition (6) for nominal money can be written as

$$\mathfrak{z}_t\frac{v'(\frac{M_t}{P_t})}{u'(C_t)} = a'_{M_t}(M_t, M_{t-1}, M_{t-2}) + \frac{1}{I_t}E_t a'_{M_t}(M_{t+1}, M_t, M_{t-1}) + 1 - \frac{1}{I_t}, \tag{9}$$

where $I_t \equiv 1+i_t$. The covariance condition holds for example if consumers are risk neutral and inflation is deterministic or if the net own-yield of money, $1-a'_{M_t}(M_{t+1}, M_t, M_{t-1})$, is deterministic. The left-hand side of equation (9) is the marginal rate of substitution of consumption for real balances. The right hand side is the rental cost, in terms of the consumption good, of holding an extra unit of real balances for one period. Note that the rental cost differs from the usual $1-1/I_t$. With quadratic adjustment costs, for example, the model might yield multiple equilibria.

Assumption 1 (Utility function and adjustment costs). Next we parameterize the utility function to the CRRA form as

$$u(C_t) = \begin{cases} \frac{1}{1-\rho}C_t^{1-\rho} & \text{if } \rho \neq 1 \\ \log C_t & \text{if } \rho = 1 \end{cases},$$

$$v\left(\frac{M_t}{P_t}\right) = \begin{cases} \frac{1}{1-\omega}\left(\frac{M_t}{P_t}\right)^{1-\omega} & \text{if } \omega \neq 1 \\ \log\left(\frac{M_t}{P_t}\right) & \text{if } \omega = 1 \end{cases}$$

and the adjustment cost function $a(\cdot)$ as follows:

$$a(M_t, M_{t-1}, M_{t-2}) = \frac{\kappa}{2}\left[(M_t - M_{t-1}) - \nu(M_{t-1} - M_{t-2})\right]^2, \tag{10}$$

where κ and ν are adjustment cost parameters.

The adjustment cost function expresses the notion that it is changes in the growth rate of money that affect costs, not the growth rate itself, as is typical (eg Cuthbertson and Taylor 1987, Cuthbertson and Taylor 1990). However, if the parameter ν is zero, the adjustment cost function is the typical one. The chosen functional form allows for persistence not only in the level of money balances but also in the growth rate of money[4]. Its motivation relies on our empirical experience with Finnish monetary aggregates. It is however difficult to connect these parameters to any spesific payment technology.

From (9) one obtains

$$\Delta M_t = \frac{1+\nu}{(1+\nu)\nu + I_t} E_t \Delta M_{t+1} + \frac{\nu I_t}{(1+\nu)\nu + I_t} \Delta M_{t-1} - \frac{1}{\kappa[(1+\nu)\nu + I_t]}(I_t - 1) + \frac{\mathfrak{Z}_t}{\kappa[(1+\nu)\nu + I_t]} I_t C_t^{\rho} \left(\frac{M_t}{P_t}\right)^{-\omega}. \quad (11)$$

The household's problem also implies the following transversality conditions:

$$\lim_{T\to\infty} \delta^T E_t \left(\frac{M_{t+T}}{P_{t+T}}\right)^{-\omega} \frac{M_{t+T}}{P_{t+T}} = 0 \quad (12)$$

$$\lim_{T\to\infty} \delta^T E_t C_{t+T}^{-\rho} C_{t+T} = 0. \quad (13)$$

The first condition (12) states that the expected real money balances cannot grow with a rate faster than $(1-\omega)/\delta$. Correspondingly, the condition (13) states that the consumption growth rate cannot exceed $(1-\rho)/\delta$. This means that exactly all the household's resources are exhausted as t approaches infinity.

2.2 Loglinear Approximation

In order to loglinearize equation (11), we find the steady state for equation (11) and then use the first-order Taylor approximation around the steady state. For the steady state, the adjustment costs are zero and $C_t = C$, $I_t = I$, $I_t = I$, $M_t = M$ $(\forall t \geq 0)$. We denote logarithmic variables in the lower case (eg $\log C \equiv c$) and $I \equiv 1 + i$. Note that $i \approx \log(1+i)$ and $\zeta_t \equiv \log(\mathfrak{Z}_t)$. In the steady state, equation (11) reduces to

$$\frac{M}{P} = \left[\mathfrak{Z} C^{\rho} \left(\frac{I}{I-1}\right)\right]^{\frac{1}{\omega}}, \quad (14)$$

which resembles the standard demand for money function. From the first-order Taylor approximation around the (log of) the steady state, we obtain the following log-linear Euler equation:

$$[I + \nu(1+\nu)]\,\Delta m_t = (1+\nu) E_t \Delta m_{t+1} + I\nu \Delta m_{t-1} + \frac{i\omega}{\kappa M}\left[\left(m - p - \frac{\rho}{\omega}c + \frac{1}{i\omega}i - \frac{1}{\omega}\zeta\right) - m_t + p_t + \frac{\rho}{\omega}c_t - \frac{1}{i\omega}i_t + \frac{1}{\omega}\zeta_t\right]. \quad (15)$$

Assumption 2. For simplicity, we assume quadratic adjustment costs, ie $\nu = 0$.

[4]Ripatti (1994) discusses on the possibility of two unit roots in the M1 and M2 series.

This simplifies the algebra but still illustrate the dynamics involved in the demand for money. The Euler equation (15) can be written as

$$\left[L^{-2}-\left(I+1+\frac{i\omega}{\kappa M}\right)L^{-1}+I\right]E_t m_{t-1}=$$
$$\underbrace{-\frac{i\omega}{\kappa M}\left(m-p-\frac{\rho}{\omega}c+\frac{1}{i\omega}i-\frac{1}{\omega}\zeta\right)}_{\equiv m^*}-\frac{i\omega}{\kappa M}\left(p_t+\frac{\rho}{\omega}c_t-\frac{1}{i\omega}i_t+\frac{1}{\omega}\zeta_t\right). \quad (16)$$

The parameterized version of Euler equation (7) is

$$1=\delta E_t\left\{(1+i_t)\frac{P_t}{P_{t+1}}\left(\frac{C_{t+1}}{C_t}\right)^{-\rho}\right\}. \quad (17)$$

The right-hand side contains the conditional expectation for a nonlinear function of random future consumption. Therefore, because of Jensen's inequality, a first-order Taylor series approximation is inadequate. The second-order Taylor approximation of Euler equation (17) gives us

$$1=\delta E_t\left\{\exp\left[\log\left((1+i_t)\frac{P_t}{P_{t+1}}\left(\frac{C_{t+1}}{C_t}\right)^{-\rho}\right)\right]\right\}$$
$$=\delta\exp\left\{E_t\left[\log(1+i_t)-\Delta\log P_{t+1}-\rho\log C_{t+1}+\rho\log C_t\right]\right.$$
$$\left.+\frac{1}{2}\operatorname{Var}_t\left[\log\left((1+i_t)\frac{P_t}{P_{t+1}}\left(\frac{C_{t+1}}{C_t}\right)^{-\rho}\right)\right]\right\}.$$

Taking logs of both sides yields

$$-\rho c_t=\log(\delta)+i_t-E_t\Delta p_{t+1}-\rho E_t c_{t+1}+v,$$

where $i_t\approx\log(1+i_t)$, $v\equiv\frac{1}{2}\operatorname{Var}_t\left[\log\left((1+i_t)\frac{P_t}{P_{t+1}}\left(\frac{C_{t+1}}{C_t}\right)^{-\rho}\right)\right]$ (which is assumed to be constant). This approximation is exact if $(1+i_t)\frac{P_t}{P_{t+1}}\left(\frac{C_{t+1}}{C_t}\right)^{-\rho}$ is lognormally distributed.

Therefore, the loglinearized Euler equation is

$$\rho E_t\Delta c_{t+1}=\log(\delta)+v+i_t-E_t\Delta p_{t+1}. \quad (18)$$

Our assumption of a constant conditional covariance might be misleading. Modelling of the variance term is nowadays an important field of research in consumption-based asset pricing theory.

2.3 Monopolistic Firms

We assume monopolistic competition[5] in order to introduce demand effects into our model. In tracking the price stickiness, we follow Rotemberg (1981)

[5]See Carlton (1996) for a critical assesment of the role of imperfect competition in macromodels.

except that we use the demand function derived from equation (11). Another widely[6] used representation is Calvo (1983). He obtains observationally similar aggregate price dynamics in a setting in which individual firms have an exogenous probability of being permitted to change the price in a given period (Rotemberg 1987).

Each monopolistic firm produces a distinct nonstorable good. The number of monopolistic firms is large and each individual firm produces such a small part of the aggregate that it need not take into account the effects of its production and pricing decisions on aggregate prices or demand.

Household consumption, C_t, is a real consumption index. Assuming CES preferences for consumption goods, a monopolistic firm faces a demand function of the form

$$C_t(z) = A(z)\left(\frac{P_t(z)}{P_t}\right)^{-\theta} C_t, \quad \theta > 1, \tag{19}$$

where $C_t(z)$ is the quantity of good z demanded at time t, which can be obtained from equation (11). $A(z)$ is a firm-specific constant, $P_t(z)$ is the price of good z at time t and P_t the general price level. The quantity demanded of any particular good depends not only on the relative price of the good but also the aggregate real consumption.

Each monopolist's cost function is quadratic:

$$K(C_t(z), z) = U(z)\Upsilon_t P_t C_t(z)^2/2.$$

The cost of producing the quantity $C_t(z)$ at time t is $K(C_t(z), z)$. $U(z)$ is a firm-specific, small and positive parameter. The production function contains an aggregate stochastic technology parameter, Υ_t. Positive changes in Υ reflect increasing costs. Hence, it is a inverse of technology or productivity shock. We call it a cost shock. In the spirit of real business cycle models, we believe that technology shocks are a key driving force in economic fluctuations. Without shocks, the model converges to a balanced growth path and then grows smoothly. In standard real business cycle models with the cash-in-advance constraint, like Cooley and Hansen (1989), the optimal policy makes no attempt to respond to technology shocks. In models with nominal rigidities, like Cho and Cooley (1995) and Yun (1996), nominal shocks affect the business cycle as well, and it is important to take the technology shock into account in designing optimal monetary policy. Ireland (1997) shows how a technology shock influences the optimal monetary policy in a model of sticky prices.

Since we assume a large number of monopolistic firms, ie that the economy is atomistic, the aggregate price level and aggregate consumption are given for each monopolistic firm. Hence, the monopolistic firm maximizes nominal profits with respect to the price of its good, $P_t(z)$

$$\pi(P_t(z)) = P_t(z)C_t(z) - U(z)\Upsilon_t P_t C_t(z)^2/2.$$

[6] See eg Yun (1996), Rotemberg and Woodford (1997), Reinhart (1992), Kollmann (1997) and King and Wolman (1996).

The first-order condition for maximization requires that $P_t(z)$ is equal to $P_t(z)^*$, where

$$P_t(z)^* = \frac{\theta}{\theta - 1} U(z) \mathcal{T}_t P_t C_t(z). \tag{20}$$

The first factor, $\theta/(\theta - 1)$, is the firm's markup. The higher the value of θ, the smaller the markup and the less the firm's monopoly power. The limiting case, $\theta \to \infty$, corresponds to perfect competition. The profit maximizing price level, $P(z)$, is the same for nominal and real profits since the individual firm's price setting does not influence the aggregate price, ie $\partial P_t / \partial P_t(z) = 0$.

Rotemberg (1981) derives the second-order Taylor approximation for profits around $P_t(z)^*$ and assumes that the monopolistic firm faces costs of changing prices[7]. The monopolist's problem can then be approximated by

$$\max_{\{p_t(z)\}} -\frac{1}{2} E_0 \sum_{t=0}^{\infty} \delta^t \left\{ [p_t(z) - p_t(z)^*]^2 + d[p_t(z) - p(z)_{t-1}]^2 \right\}. \tag{21}$$

The first-order condition is

$$\delta d E_t \Delta p_{t+1}(z) - d \Delta p_t(z) = p_t(z) - p_t(z)^*, \tag{22}$$

where a lowercase letter denotes the logarithm of the variable denoted by the corresponding uppercase letter and $\tau_t \equiv \log \mathcal{T}_t$. Note that the time preference parameter, δ, is the same for consumers and producers. The current change in the price of product z is determined by the optimal (in the absence of adjustment costs) price level rise compared to the present level and the expected future level. Due to the adjustment costs in changing price, the firm must take into account the expected future optimal prices.

The maximization problem also involves a transversality condition:

$$\lim_{T \to \infty} E_t \delta^T \left[(p_{t+T}(z) - p_{t+T}(z)^*) + d(p_{t+T}(z) - p_{t-1+T}(z)) \right] = 0. \tag{23}$$

In the aggregation we utilize the demand function faced by the firm. The aggregated[8] version of equation (22) is

$$\delta d E_t p_{t+1} - (d + \delta d) p_t + d p_{t-1} = -S - D(c_t + \tau_t), \tag{24}$$

[7]Arguments for the costs in changing prices can be classified into two categories (see eg Barro (1972) and Sheshinski and Weiss (1977)): administrative and similar costs (menu costs; see Levy, Bergen, Dutta and Venable (1997) for empirical relevance) and costs due to unfavourable reactions by customers. Rotemberg (1987) illustrates that increasing prices could, for example, upset customers. However, the quadratic adjustment cost approach assumes symmetry in the costs of raising or lowering prices. Prescott (1987, page 113) critizes the menu cost approach:"I have no answer to the question of how to measure these menu change costs, but these theories will never be taken seriously until an answer is provided". Nevertheless, we treat the assumption of the menu costs as merely a simplifying device to introduce price inflexibility into our model. On a more fundamental level, the problem remains as to how to explain the apparently significant costs of changing prices.

[8]In the aggregation we approximate the CES consumption price index with a Cobb-Douglas price index using the weights $h(z)$. In the limiting case, $\theta \to 1$, the approximation is exact.

where $S \equiv \int_0^1 \frac{1}{\theta+1} h(z) \left[\log\left(\frac{\theta}{\theta-1}\right) + u(z) + a(z)\right] dz$ and $D \equiv \frac{1}{\theta+1}$. Let λ denote the stable root of the corresponding characteristic equation $\frac{1}{\delta}+1 = \lambda + \frac{1}{\lambda}$. The Euler equation (24), in the first difference form, is

$$d\delta E_t \Delta p_{t+1} - d\Delta p_t = -S - D(c_t + \tau_t).$$

It is also assumed that all monopolistic firms have homogenous expectations about all the random variables in the system, ie about c_t and τ_t. Consequently, the forward solution is

$$p_t = \frac{S}{1-\lambda} + \frac{1}{\lambda\delta} p_{t-1} + \frac{D}{d\delta} E_t \sum_{j=0}^{\infty} \left(\frac{1}{\lambda}\right)^j (c_{t+j} + \tau_{t+j}) \tag{25}$$

or in difference form

$$\Delta p_t = \frac{S}{d(1+\delta)} + \frac{D}{d\delta} E_t \sum_{j=0}^{\infty} \delta^j (c_{t+j} + \tau_{t+j}). \tag{26}$$

According to the solution, the firms must consider the past price level and forecast the future aggregate demand as well as the cost shocks in order to determine its current price level. The aggregate demand links the consumption decision of the representative household and the pricing decision of the monopolistic firm.

The quadratic adjustment cost approach has the advantage of yielding equations that can be easily estimated. Calvo's approach shares this quality. The drawback of the model is that the adjustment cost parameter is fixed; even in a regime of large and sudden increases in aggregate demand the prices adjust rather slowly. In Calvo's model, individual price changes can be large while the price level adjusts sluggishly. There is also a mapping from the adjustment cost parameter of the present model to the probability of price changes in Calvo's model.

Another implicit assumption concerning the adjustment costs of price changes is the symmetry and state-independence of the cost parameter, d. There is however only weak evidence of asymmetries in the GDP (Hess and Iwata 1997). State-independence in possibly a more restrictive assumption. For example, it might be the case that in a high inflation regime the adjustment costs are larger than in the case of a low inflation regime.

2.4 Steady State

To construct the steady state and to derive the equilibrium, we write our Euler equations as

$$\left[L^{-1} - \left(1 + I + \frac{\omega i}{\kappa M}\right) + IL\right] E_t m_t = m^* \\ -\frac{\omega i}{\kappa M} E_t \left(p_t + \frac{\rho}{\omega} c_t - \frac{1}{\omega i} i_t + \frac{1}{\omega}\zeta_t\right), \tag{27}$$

$$\left[L^{-1} - \left(\frac{1}{\delta}+1\right) + \frac{1}{\delta}L\right] E_t p_t = -\frac{S}{d\delta} - \frac{D}{d\delta} E_t (c_t + \tau_t), \tag{28}$$

$$(L^{-1} - 1) E_t p_t + \rho (L^{-1} - 1) E_t c_t = \log\delta + v + E_t i_t, \tag{29}$$

where $L^{-j}E_t x_t = E_t x_{t+j}$. Utilizing equations (27)–(29) and the steady state relationship (14), we obtain steady state solutions by letting $L = 1$. We use 'bar' notation for steady state values for each variable. The steady state is determined by the following equations:

$$\bar{c} = -\bar{\tau} - \frac{S}{D}, \tag{30}$$

$$\bar{i} = -\log\delta \quad \text{and} \tag{31}$$

$$\bar{p} = \bar{m} + \frac{\rho}{\omega}\bar{\tau} - \frac{1}{\omega}\bar{\zeta} + \frac{\rho S}{\omega D} + \frac{\log\delta + \log(-\log\delta)}{\omega}. \tag{32}$$

The steady state properties of the model are quite classical. The steady state consumption level is determined by supply factors, ie the steady state cost shocks and the aggregated parameters of the cost function of the monopolistic firm. Since there is no inflation in the steady state, the nominal interest rate equals the real rate of interest. Since the conditional covariance, v, is zero in the steady state, the real and nominal rate equals $1/\delta - 1$, ie the degree of time preference. As in any classical model, the price level is left undetermined. However, the real balances are determined by the steady state cost and preference shocks and all the other parameters of the model. If the money stock is given, the price level is determinated by the model and *vice versa*. The higher the average costs, the lower the real money balances. The more weight that households give to real money balances, ie the more liquidity services money yield, the higher the steady state level of real money balances. The steady state also corresponds to the temporal equilibrium of the model in the situation where the adjustment costs for both money and prices are zero.

2.5 Equilibrium

An equilibrium is a set of stochastic processes $\{m_t, p_t, c_t\}_{t=0}^{\infty}$ satisfying equilibrium conditions (15), (18) and (24), given m_{-1}, m_{-2}, m_{-3}, p_{-1}, p_{-2}, c_{-1}, c_{-2} and $\{i_t, \tau_t, \zeta_t\}_{t=0}^{\infty}$.

First we combine the Euler equations (18) and (24) in order to solve for inflation and consumption growth. We discuss the possible equilibria that these equations yield. The solution for money can then be obtained by using the solutions for inflation and consumption growth. Equilibrium consumption is characterized by the following equation:

$$\begin{aligned} c_t = {} & \frac{1}{\delta\lambda_p}c_{t-1} + \frac{1}{\delta\lambda_p}(\log\delta + v + i_{t-1}) \\ & - \frac{1}{\lambda_p}\left(1 - \frac{1}{\delta\lambda_p}\right)E_t\sum_{j=0}^{\infty}\left(\frac{1}{\lambda_p}\right)^j(\log\delta + v + i_{t+j}) \\ & - \frac{D}{d\delta\rho\lambda_p}E_t\sum_{j=0}^{\infty}\left(\frac{1}{\lambda_p}\right)^j\left(\tau_{t+j} - \frac{S}{D}\right) \end{aligned} \tag{33}$$

where $|\lambda_p| > 1$ is one of the roots[9] of $\frac{\delta+1}{\delta} + \frac{D}{d\delta\rho} = \lambda + \frac{1}{\delta\lambda}$. Clearly the dynamic sollution to the consumption displays saddle path dynamics; current consump-

[9] It can be shown that the roots are $|\lambda_p| > 1$ and $|1/(\delta\lambda_p)| < 1$.

tion depends on past consumption as well as on the entire anticipated future path of interest rates and cost changes. This property of a rational expectations solution is general and shows up in many types of rational expectations models. Past interest rates have a positive effect on current consumption, whereas present and future interest rates affect it negatively. The term $\frac{1}{\lambda_p}\left(1-\frac{1}{\delta\lambda_p}\right)$ has a positive sign. This is a reflection of the familiar consumption smoothing behaviour of households under well-functioning capital markets.

The dynamic relationship between inflation and interest rates is not as straightforward as the relationship between consumption and interest rates. As above, we combine the Euler equations (18) and (24) and, then, substitute for consumption; yielding

$$E_t\Delta p_{t+2}-\left(1+\frac{1}{\delta}+\frac{D}{d\delta\rho}\right)E_t\Delta p_{t+1}+\frac{1}{\delta}\Delta p_t = -\frac{D}{d\delta\rho}\left[i_t+(\log\delta+v)+\rho E_t\Delta\tau_{t+1}\right]. \quad (34)$$

The characteristic equation is as above. Then we solve forwardly the unstable root, λ_p:

$$\left(1-\delta\lambda_p L^{-1}\right)E_t\Delta p_t = -\frac{D\lambda_p}{d\rho}E_t\sum_{j=0}^{\infty}\left(\frac{1}{\lambda_p}\right)^j\left(i_{t+j}+\log\delta+v+\rho\Delta\tau_{t+1+j}\right). \quad (35)$$

Note however that we still have the stable root, $|\delta\lambda_p|>1$. This is a well known problem in macroeconomic models where the 'IS function' contains an expected endogenous variable (see eg Kerr and King (1996) and references therein). The maibn point here is that the future inflation has a greater than one-for-one effect on current inflation. We discuss two possible candidates for equilibria.

With the first candidate, the solution displays saddle-path dynamics and can be written explicitely as

$$\Delta p_t=\frac{1}{\delta\lambda_p}\Delta p_{t-1}+\frac{D}{d\delta\rho\lambda_p}E_t\sum_{j=0}^{\infty}\left(\frac{1}{\lambda_p}\right)^j\left(i_{t-1+j}+\log\delta+v+\Delta\tau_{t+j}\right).$$

This solution however yields a *positive relationship between future interest rates and inflation.* Increases for example in the current nominal interest rate while keeping the path of (anticipated) future interest rates constant increase current inflation. Whereas it is well known that rational expectations solutions can display non-standard dynamics in certain model types[10], we conjencture that in the present context this 'perverse' dynamic relationship reflects unstable dynamics.

[10] See eg the (overlapping generations) model of inflation analyzed by Sargent (1993), where increased government deficits reduce inflation in a stable rational expectations equilibrium. The reason is that the economy finds itself in the wrong side of the 'Laffer' curve in the inflation tax rate.

The second candidate for the forward solution of (35) clarifies the feasibility of the possible choices of interest rate paths. We iterate it T periods forward:

$$\Delta p_t = \frac{D}{d\rho}\left\{\frac{1}{\lambda_p - \frac{1}{\delta\lambda_p}} E_t \sum_{j=0}^{T} \left[(\delta\lambda_p)^j \lambda_p - \lambda_p^{-j}(\delta\lambda_p)^{-1}\right]\right.$$
$$\times \left(i_{t+j} + \log\delta + v + \rho\Delta\tau_{t+1+j}\right)$$
$$+ \frac{1}{\delta(\lambda_p - \frac{1}{\delta\lambda_p})}\left[(\delta\lambda_p)^{T+1} - \left(\frac{1}{\lambda_p}\right)^{T+1}\right] E_t \sum_{j=T+1}^{\infty} \left(\frac{1}{\lambda_p}\right)^{j-(T+1)}$$
$$\left. \times \left(i_{t+j} + \log\delta + v + \rho\Delta\tau_{t+1+j}\right)\right\} + (\delta\lambda_p)^{T+1} E_t \Delta p_{t+T+1}. \quad (36)$$

The dynamics of the equilibrium inflation has Wicksellian features. Any interest rate peg which sufficiently differs from the degree of time preference and expected cost change will destabilize inflation. The current inflation is dominated by the long-term expectations for future inflation. Consequently, the interest rates should be set as to yield zero inflation on the average in the long run. This also means that the central bank must on average relate the nominal interest rate to the expected next-period cost shock, $-\rho\Delta\tau_{t+1}$, and steady-state interest rate, $\log\delta + v$.

The last term, $(\delta\lambda_p)^{T+1} E_t \Delta p_{t+T+1}$, which represents the aggregated transversality condition (23) of inflationmust be zero. The first partial sum in the braces, which describes the expected future, up to period T, is in general bounded only with finite T. The discount factor, $(\delta\lambda_p)^j\lambda_p - \lambda_p^{-j}(\delta\lambda_p)^{-1}$, is greater than unity and thus restricts the speed of mean reversion of the linear combination of interest rates and cost changes. For certain paths of $z_t \equiv i_{t+j} + \log\delta + v + \rho\Delta\tau_{t+1+j}$, the first term will be bounded even in the limiting case as T approaches infinity. The second partial sum represents the expectations from the period $T+1$ onwards. Its discount factor is less than unity but the expectation term is multiplied by a factor that is greater than unity and raised to the power $T+1$. This puts restrictions on the very distant path of process z_t and it must approach zero as T approaches infinity.

Note that in the above equilibria, the greater the cost of changing prices, d, the less the influence of monetary policy (ie the interest rate) on the inflation. This is due to the rigidity of changing prices. In this sense, the model is not very classical in the short run. The price rigidity is exogenous with respect to monetary policy and with respect to the level of inflation. This is probably an unrealistic assumption for a high inflation regime. In the more realistic case, the adjustment cost would be linked to the level of inflation. King and Wolman (1996) discuss this possibility in the context of the Calvo's price setting.

Finally, the solution for money growth is given by the following equation:

$$\Delta m_t = \frac{i(\log\delta + v)\left[D(\omega-1) - d\delta\rho\right]}{\kappa M d\rho\delta(1-\lambda_m)(1-\lambda_p)} + \left(\frac{I}{\lambda_m} + \frac{1}{\delta\lambda_p}\right)\Delta m_{t-1} - \frac{I}{\delta\lambda_p\lambda_m}\Delta m_{t-2}$$

$$+ \frac{1}{\kappa M(\frac{\lambda_m}{\lambda_p}-1)} E_t \sum_{j=2}^{\infty}\left[\left(\frac{1}{\lambda_m}\right)^j - \left(\frac{1}{\lambda_p}\right)^j\left(\frac{\lambda_p}{\lambda_m}\right)\right]\left\{L - \left(\frac{1}{\delta} - i + \frac{D}{d\delta\rho}\right)L^2\right.$$

$$\left. + \left[\frac{D}{d\delta\rho}(1+\omega i) + i + 1 + \frac{1}{\delta}(2+i)\right]L^3 - \frac{1}{\delta}(1+i)L^4\right\} i_{t+j}$$

$$- \frac{i}{\kappa M(\frac{\lambda_m}{\lambda_p}-1)} E_t \sum_{j=2}^{\infty}\left[\left(\frac{1}{\lambda_m}\right)^j - \left(\frac{1}{\lambda_p}\right)^j\left(\frac{\lambda_p}{\lambda_m}\right)\right]\left[L - \left(\frac{1}{\delta} + 1 + \frac{D}{d\delta\rho}\right)L^2\right.$$

$$\left. + \frac{1}{\delta}L^3\right]\Delta\zeta_{t+j} \qquad (37)$$

$$+ \frac{iD}{\kappa M d\delta(\frac{\lambda_m}{\lambda_p}-1)} E_t \sum_{j=2}^{\infty}\left[\left(\frac{1}{\lambda_m}\right)^j - \left(\frac{1}{\lambda_p}\right)^j\left(\frac{\lambda_p}{\lambda_m}\right)\right](\omega L^2 - L^3)\Delta\tau_{t+j},$$

where $|\lambda_m| > 1$ is one of the roots of $1 + I + \frac{\omega i}{\kappa M} = \lambda + \frac{I}{\lambda}$. Money growth does not have any feedback to the solutions for inflation and consumption growth. Consequently, it does not have any role in an inflation targeting monetary policy using an interest rate instrument. Equilibrium is determined by expected future interest rates, cost shocks and velocity shocks. The existence of velocity shocks adds an extra complication to monetary targeting. The central bank will need to know the stochastic characteristics of the velocity shocks.

3 Inflation Targeting and Monetary Policy Strategy

Our model describes the dynamic relationship between money, prices, consumption and interest rates. The model includes two types of exogenous shock: a preference shock in the money-in-the-utility-function and an aggregate cost shock to production. So far we have treated interest rates as being predetermined, ie we have analysed the equilibria given an exogenous path of expected interest rates. In this section we give a more profound characterization of the equilibrium. In section 3.1 we characterize the possible interest rate path given the preference for finite inflation. Section 3.2 gives more precision to concept of inflation targeting. We compare direct inflation targeting to inflation-expectations targeting. Then in section 3.3 we utilize the Euler equation for money to study the equilibrium, where inflation is determined by current money growth and lagged other variables.

The model has interesting implications for monetary policy strategy. Inflation (see equation (36)) is determined by the discounted sum of *expected future interest rates* and discounted expected future cost changes. If interest rates are controllable by the central bank[11], there is a direct channel from the monetary policy instrument to inflation.

[11]Most of the central banks do control the short-term interest rates: two weeks repo rate

The equilibrium inflation is characterized by knife-edge dynamics: if expected interest rates and cost changes diverge by too much for too long from each other and from the steady-state interest rate, the result will be destabilizing inflation. The equilibrium exhibits the kind of behaviour which was studied by Knut Wicksell already in the early part of the century (see Wicksell 1936). Since the discount factor for the forward sum is greater than unity, it determines the speed at which the linear combination of interest rate and cost change converges to zero. We discuss the feasibility of interest rate paths in section 3.1.

We extend the analysis to the case where the central bank aims to stabilize inflation or inflation expectations. In the former case inflation is fixed at the target rate, whereas in the latter case shocks cause inflation to diverge from the targeted rate. The differences are due to information differences between households and firms *versus* the central bank. The central bank must make the first move. Different cases arise depending on whether nature moves before or after the central bank, ie whether the shocks occur before or after the central bank moves. We compare these rules to the classical case in which interest rates are conditioned on current inflation. It turns out that the classical case does not necessarily lead to a constant inflation rate, whereas the other rules do.

Finally we are able to show that money has a particular feature in our setup. Because of the adjustment costs on money balances, we find an equilibrium where money can be used as an anchoring device for inflation. The central bank can even use a money rule whereby money growth is conditioned on the period $t-1$ information of the state variables. This gives the central bank a device for controling inflation with a lagged information set. However, the central bank needs to know the parameters of the 'money demand' equation.

3.1 Feasible Interest Rate Paths

In this section we discuss the possible interest rate paths for given stochastic specification of the cost process, given the aim of finite inflation. We discuss first some general results and then the restrictions on the interest rate process for the case in which the expected cost change is constant.

The forward solution (36) can be written as

$$\Delta p_t = -\frac{D}{d\rho(\delta\lambda_p - \lambda_p^{-1})} E_t \sum_{j=0}^{\infty} \left[(\delta\lambda_p)^j - \left(\frac{1}{\lambda_p}\right)^j \right] (i_{t-1+j} + \log\delta + v + \rho\Delta\tau_{t+j}). \tag{38}$$

Since $|\delta\lambda_p| > 1$ and $|1/\lambda_p| < 1$, the discount factor, $(\delta\lambda_p)^j - \left(\frac{1}{\lambda_p}\right)^j$, is greater than one. The discount factor restricts the feasible path of the interest rate and cost growth processes. Assuming an autoregressive process for the weighted sum of the interest rate and cost change processes $z_t \equiv i_t + \log\delta + v + \rho\Delta\tau_{t+1}$, ie $\mathfrak{a}(L)z_t = \varepsilon_t^z$ (where ε_t^z is identically and indepently distributed with zero mean) we can prove the following proposition:

(the Bundesbank, the Swedish Riksbank), one month tender rate (the Bank of Finland), FED funds rate (Federal Reserve), etc.

Proposition 1. Assuming that $z_t \equiv i_t + \log\delta + v + \rho\Delta\tau_{t+1}$ follows an autoregressive process $\mathfrak{a}(L)z_t = \varepsilon_t^z$ with ε_t^z independently and identically distributed with mean zero, inflation will be finite if the absolute value roots of $|\mathfrak{a}(L)| = 0$ are greater than $\delta\lambda_p$.

The proof follows from the discount term, which is at most of the order $\delta\lambda_p$. However in general there is no need to be restricted to the class of linear interest rate processes.

The proposition is not readily applicable and does not lead to unconditional[12] interest rate rules unless we parameterize the process driving cost changes. It asserts that the expected cost change (which could be negative on the average) and interest rate should not diverge but should instead converge at least with a the rate that is limited by the $1/\delta\lambda_p$. The absolute requirement for inflation-stabilizing monetary policy, given the cost-change process, is to choose the parameters of the interest rate process so that they satisfy the condition in proposition 1. Hence, by the very nature of rational expectations, the policy is a sequence of the relevant control variable — not a single point at a single point of time. Accordingly, the policy is generally not defined by a single point for the interest rate but rather by the parameters of the interest rate process. If the monetary policy is aimed at stabilizing inflation, policymakers must choose the parameters of the interest rate process according to proposition 1. Consequently the parameters of the interest rate process depend on the parameters of the cost change process.

Consider, for example, tge case where $E_t\Delta\tau_{t+1} = \tau^\star$ and z_t is assumed to follow an AR(1) process

$$i_t = -(\log\delta + v) - \rho\tau^\star + \iota(i_{t-1} + \log\delta + v + \rho\tau^\star) + \varepsilon_t^\iota,$$

where ε_t^ι is a zero-mean independent process[13]. The j period conditional forecast is then $E_t i_{t+j} = \iota^j(i_t + \log\delta + v + \rho\tau^\star)$. The expectation part of equation (38) is then $E_t\sum_{j=1}^{\infty}[(\delta\lambda_p)^j - (1/\lambda_p)^j]\iota^j(i_t + \log\delta + v + +\rho\tau^\star)$, which is finite if $|\iota| < 1/\delta\lambda_p$. Monetary policy in a world of constant cost growth is fairly simple. In order to keep inflation bounded, the central bank must choose the parameters of the interest rate process so that its degree of mean reversion is strong enough. The central bank need not to react to innovations in costs. All it must do is to fix the parameters of the interest rate process so that they satisfy the condition of proposition 1. In the above AR(1) example, the change in policy implies a different choice of ι.

In the general case, where the expected cost change is not a constant, monetary policy must react to innovations in the expected growth rate for costs but not to innovations in the level for costs. Due to this fact the interest rates must be changed for every period when a shock occurs to the growth rate of $\Delta\tau_t$. However, a change in the interest rates is not a monetary policy change since it is the parameters of the interest rate process that define the monetary policy. It is also implicitly assumed that the central bank can commit itself to an interest rate rule.

[12]By the term *unconditional rule* we mean a rule that is independent of the state of the economy, eg a constant money growth rules.

[13]We need not assume homoscedasticity. Note that it is not necessary to define the policy shocks, ε_t^ι.

3.2 Targeting Inflation or Inflation Expectations

In this section we study three cases. In the first case the central bank (monetary authority) targets a constant inflation rate, $\Delta p_t = \pi^\star$. This leads to a sufficient condition for determining the interest rate rule. The policy rule that results is optimal in the case where the central bank has a direct inflation target and a quadratic objective function with respect to the deviations of inflation from the target. The second case assumes that in each period the central bank must set the interest rate path before the cost and velocity shocks occur, ie such shocks are not known by the central bank when it makes its interest rate decision. Svensson (1996) refers this as inflation forecast targeting, $E_{t-1}\Delta p_t = \pi^\star$. Finally we investigate the pure feedback rule proposed by Kerr and King (1996), where the interest rates are set on the basis of feedback from current inflation.

To fix inflation at a given rate, we replace the actual inflation in equation (38) with targeted inflation, $\pi^\star$, and solve for the current interest rate:

$$i_t = -\rho E_t \Delta\tau_{t+1} + \frac{\log\delta + v}{(\delta\lambda_p - \lambda_p^{-1})^2} - \frac{d\delta}{D}\pi^\star - \frac{1}{\delta\lambda_p - \lambda_p^{-1}} E_t \sum_{j=2}^{\infty} \left[(\delta\lambda_p)^j - \lambda_p^{-j}\right](i_{t-1+j} + \rho\Delta\tau_{t+j}). \quad (39)$$

According to the resulting interest rate rule, the interest rate should be set in line with the expected cost change and targeted inflation rate, $\pi^\star$. In addition to this the central bank ties its hands for the future by announcing the interest rate path that is in line with targeted inflation. The convergence results hold for this infinite sum as in section 3.1.

The central bank could eg in the case of expected falling costs announce that in order to reach the targeted inflation today it will raise interest rates only in the future. It could even lower the current interest rates today if it can commit to raising them in the future. By means of such an announcement, it could not only postpone the interest rate change but also achieve inflation of $\pi^\star$. However, this policy cannot be pursued forever because the transversality condition (23) restricts the possibility of postponing the decision. In general, the model allows the central bank to choose any kind of inflation path (within the limits of the transversality condition) by announcing a suitable interest rate path with respect to expected cost changes.

A sufficient condition for achieving the targeted inflation, $\pi^\star$, can be obtained by replacing the expected and actual inflation rates in Euler equation (34) by targeted inflation rate $\pi^\star$, and solving for the current interest rate. We obtain the following interest rate rule:

$$i_t = \pi^\star - (\log\delta + v) - \rho E_t \Delta\tau_{t+1}. \quad (40)$$

The outcome of the inflation targeting policy is that the central bank must set the interest rate according to expected cost change and inflation target minus the steady state interest rate in order to keep inflation at the targeted rate, $\pi^\star$. If we assume a constant cost growth of $\tau^\star$, the constant interest rate

$i_t = \pi^\star - (\log\delta + v) - \rho\tau^\star$ stabilizes inflation at $\pi^\star$. This however is not the case when the cost process is not a martingale with drift.

We consider the following example, where the cost change follows the first order autoregressive process $\Delta\tau_t = \beta\Delta\tau_{t-1} + \varepsilon_t^\tau$. The interest rate rule is then $i_t = \pi^\star - (\log\delta + v) - \rho\beta\Delta\tau_t$. Hence, the interest rates vary over time as the cost changes vary. It is also clear that there must not be any parameter uncertainty, ie the cost change process must be known. Note that the above discussion on shocks also applies here. The central bank need not react to shocks to the level of costs if these do not change the growth rate for costs.

We resuffle the sequence of decisions by assuming that the interest rate is set before the current cost and velocity shocks take place. Consequently, the interest rate can be conditioned on period $t-1$ information only. The conditional interest rate rule can be obtained from (40) as

$$E_{t-1}i_t = \pi^\star - (\log\delta + v) - \rho E_{t-1}\Delta\tau_{t+1}. \tag{41}$$

We note that here the central bank must forecast even the current cost change. The realization of the period t cost change may deviate from the expected one and thus the current inflation may differ from $\pi^\star$. We denote the update of the cost change expectations as $\epsilon_t^{\Delta\tau} \equiv E_t\Delta\tau_{t+1} - E_{t-1}\Delta\tau_{t+1}$. Since the central bank cannot know the shocks for period t, it cannot directly control the inflation. Inflation is then determined by the target and the expectations update, ie $\Delta p_t = \pi^\star + \epsilon_t^{\Delta\tau}$.

We may interprete the above equation as the optimal rule under strict inflation targeting when the central bank uses the inflation forecast as the intermediate target (see Svensson 1996). Households and firms know the value of current costs when they make their decisions on money, consumption and prices. Consequently they do not make mistakes in setting the current inflation. Given the above example, where cost change follows a first-order autoregressive process, we note that the central bank observes the interest rate rule $E_{t-1}i_t = \pi^\star - (\log\delta + v) - \rho\beta^2\Delta\tau_{t-1}$. In such an autoregressive case, it can replace the period $t-1$ cost change with that period's inflation. The rule $E_{t-1}i_t = \pi^\star - (\log\delta + v) - \rho\beta(\Delta p_{t-1} - \pi^\star) - \rho\beta^3\Delta\tau_{t-2}$ is equivalent with the above rule. When we iterate the rule backwards, we end up with the following distributed lag version of the rule:

$$\begin{aligned} E_{t-1}i_t &= \pi^\star - (\log\delta + v) - \rho\sum_{j=1}^{t}\beta^j(\Delta p_{t-j} - \pi^\star) \\ &= (1-\beta)\pi^\star - (1-\beta)(\log\delta + v) - \beta\rho(\Delta p_{t-1} - \pi^\star) + \beta E_{t-2}i_{t-1}. \end{aligned} \tag{42}$$

Hence, the central bank can condition the current interest rate on the whole inflation history instead of on the expected cost change. Another interpretation is that setting of the current interest rate must be conditioned on the last deviation from target and the last interest rate setting. This is due to the autoregressive cost change process and is not a general result. Also in this particular case the cost process parameters (here β) must be known.

The first interest rate rule (40) is designed to imply a fixed inflation rate. However, there is nothing in rule (41) that guarantees the finiteness of current inflation. Using the definition of $\epsilon_t^{\Delta\tau}$ we can manipulate the rule to get

$$z_t \equiv E_{t-1} i_t + \rho E_{t-1} \Delta\tau_{t+1} = \pi^\star - (\log\delta + v) + \rho\epsilon_t^{\Delta\tau}.$$

According to proposition (1) the rule guarantees finite current inflation only if the expectation revisions are sufficiently mean-reverting. Although this is the case in a rational expectations framework, it might not be the case in certain adaptive expectations schemes.

Third, we consider the following situation wherein the central bank operates a feedback rule of the form

$$i_t = \underline{i} + g(\Delta p_t - \pi^\star), \text{ where } g \geq 0. \tag{43}$$

This rule is analyzed eg by Parkin (1978), McCallum (1981) and Kerr and King (1996). We append this 'nominal anchor' to the equilibrium relationship (38). The result is that Euler equation (34) reduces to

$$E_t\Delta p_{t+2} - \left(1 + \frac{1}{\delta} + \frac{D}{d\delta\rho}\right) E_t\Delta p_{t+1} + \left(\frac{1}{\delta} + \frac{D}{d\delta\rho} g\right)\Delta p_t = - \frac{D}{d\delta\rho}\left(\log\delta + v + \underline{i} - g\pi^\star + \rho E_t\Delta\tau_{t+1}\right). \tag{44}$$

It can be shown that the roots of the characteristic polynomial of Euler equation (44) are both greater than unity if $g > 1$ and both sides of the unit circle if $0 \leq g < 1$. When $g > 1$, the central bank reacts forcefully to deviations of inflation from target. In this case the inflation is bounded if the cost changes are bounded. Without the costs, this is same result as in Kerr and King (1996). What differs is the fact that *the exact inflation target can be achieved with this rule only in the case where the expected cost changes are constant.* From the above, it follows that the central bank must explicitely take into account the expected cost change in deciding on the interest rate rule. With an autoregressive cost process, the central bank can condition the interest rate on past inflation but it must also condition the interest rate on past cost changes. There is no escape from conditioning the interest rate rule on cost information. Our result is very much like deriving from the analysis by Ireland (1997).

3.3 Money as Nominal Anchor

In this section we explore the case where the central bank uses money as a nominal anchor. Money has a special role in our framework. We show how money replaces the expectations as to future technology shocks and discuss how the central bank can use the current growth of nominal balances as a monetary policy instrument. Since money growth incorporates the above-mentioned expectations, it follows that money can be a robust monetary policy instrument.

We solve for consumption from the Euler equation for prices (29) and substitute it into the Euler equation for money (27). We end up with the following stochastic difference equation:

$$(L^{-1} - 1/\delta)E_t\Delta p_t = -\frac{1}{d\delta}\left(S + \frac{D\kappa M}{\rho i}m^*\right)$$
$$+ \frac{D\kappa M}{d\delta\rho i}\left[L^{-1} - \left(1 + I + \frac{\omega i}{\kappa M}\right) + IL\right]E_t m_t$$
$$+ \frac{D\omega}{d\delta\rho}E_t\left(p_t - \frac{1}{\omega i}i_t - \frac{\rho}{\omega}\tau_t + \frac{1}{\omega}\zeta_t\right).$$

Note that $|1/\delta| > 1$. This equation has the following interesting deterministic backward solution:

$$\Delta p_t = -\frac{1}{d\delta}\left(S + \frac{D\kappa M}{\rho i}m^*\right) + \frac{1}{\delta}\Delta p_{t-1} + \frac{D\kappa M}{d\delta\rho i}\Delta m_t + \frac{D\kappa MI}{d\delta\rho i}\Delta m_{t-1}$$
$$- \frac{D\omega}{d\delta\rho}\left(m_{t-1} - p_{t-1} + \frac{1}{\omega i}i_{t-1} + \frac{\rho}{\omega}\tau_{t-1} - \frac{1}{\omega}\zeta_{t-1}\right). \quad (45)$$

The coefficient of current money changes determines the positive relationship between money growth and inflation. This relationship enables the control of inflation by controlling money growth. The sign of the loading coefficient, $-\frac{D\omega}{d\delta\rho}$, motivates the results for the estimation of the money demand system, as in Ericsson and Sharma (1996).

Another line of interpretation of the relationship is that money serves as an important information variable on inflation. It replaces the discounted sum of expected interest rates and expected future cost changes. Consequently, the relationship is also usefu to a central bank with an interest rate instrument and a direct inflation target. In fact, if the central bank is uncertain about the precise parameterization of the stochastic process for cost change or there is simply a great deal of uncertainty as to future cost shocks, the bank can use money as an indicator of public expectations as to future cost changes and interest rates.

This particular contemporaneous relationship arises from the adjustment costs of changing money holdings. In the case of zero adjustment costs of money ($\kappa = 0$), the money growth terms vanish and the equation contains only lagged inflation and the error correction term, ie the last term in parentheses. In such a case the inflation could not directly be controlled by the money instrument. Hence the contemporaneus relationship between inflation and money growth is a unique feature of the model at hand, not a feature of the MIUF model in general.

Replacing current inflation, Δp_t, with targeted inflation, $\pi^\star$, we obtain the following money growth rule:

$$\Delta m_t = \frac{\rho i}{D\kappa M}\left(S + \frac{D\kappa M}{\rho i}m^* + d\delta\pi^\star\right) - \frac{d\rho i}{D\kappa M}\Delta p_{t-1} + I\Delta m_{t-1}$$
$$+ \frac{\omega i}{\kappa M}\left(m_{t-1} - p_{t-1} + \frac{1}{\omega i}i_{t-1} - \frac{1}{\omega}\zeta_{t-1} + \frac{\rho}{\omega}\tau_{t-1}\right). \quad (46)$$

We see that the central bank can precisely determine the period t inflation rate by relying solely on information known at the end of period $t-1$. Only the period $t-1$ realizations of τ_{t-1} and ζ_{t-1} need to be known. One need not to know the stochastic specification of the shocks. Hence, the money rule of equation (46) is robust with respect to the stochastic processes for τ_t and ζ_t. The central bank can control inflation exactly even if the money supply is set at the start of period t, ie before period t shocks occur.

There is no free lunch here either: equation (45) can be utilized only in the case where the parameters of the relationship (27) are known. The parameters that must be known, in addition to the parameters in the interest rate rules, are the level of adjustment costs, κM, the mean of steady state, m^*, and the linearization point of interest rate, i.

The form of the relationship described by equation (46) is, in a sense, a formulation of the Bundesbank approach[14]. The German Bundesbank sets its money growth target as the sum of growth rates (targets) for prices, velocity and potential output. Here $\frac{1}{i\omega}i_t - \frac{1}{\omega}\zeta_t$ presents the velocity term, which is partly independent of monetary policy and depends on the time-varying liquidity services that money provides; negative changes in $\frac{\rho}{\omega}\tau_t$ represent advances in potential output. The relationship between real money balances, interest rates, and preference and technology shocks represents the steady state relationship to which the system converges. The rest of the equation represent the adjustment dynamics for inflation and money.

4 Demand for Money and Monetary Policy

We conclude the study by discussing the role of the demand for money in a monetary policy framework wherein the central bank has an inflation target. To some extent, this discussion is connected with the discussion on the choice of monetary policy instrument initiated by Poole (1970).

Our model is based on the money-in-the-utility-function approach augmented with a sticky price supply side equation. The special characteristic of the model is the adjustment costs of money balances. The driving forces of the system arise from the aggregate cost shocks as well as from the shocks to preferences regarding real money balances. The Euler equation for money determines either money balances or interest rates. Consumption is determined by the Euler equation for bonds. Finally, the adjustment costs for changing prices lead to the Euler equation for inflation.

The equilibria determined by the last two Euler equations fully characterize the relationship between inflation and interest rates given the expected cost change. In this respect, money is not needed in the model in order to control inflation. In such a case, the first Euler equation simply determines the money holdings. An interest rate rule that targets constant inflation or inflation expectations must be conditioned on the expected cost change. This is one of the main findings of the study. In the more realistic situation when the shocks for period t are not known by the central bank, the inflation cannot be targeted at all. In that case only the inflation expectations can be targeted. The only exception is the most simplistic case wherein the cost change is constant over time. However, in general, precise estimation of the cost process may be

[14] See eg Deutsche Bundesbank (1997) or any other January issue of its monthly report.

impossible or at least very difficult, and stability of the technology process is a very heroic assumption. In such a case the inflation targeting rule cannot be found. One can say in summary that it is possible to reach the inflation target using the interest rate instrument only if the cost process is known.

We also show that in the case of adjustment costs for nominal money balances there exists an equilibrium in which current money growth determines current inflation. This is also the outcome in the models with no friction in prices or money. However, this classical result is not generally present in sticky price models. The introduction of adjustment costs in changing money holdings leads to this result in our setup. Monetary policy can be based on money as an instrument or money as an intermediate target. This approach is robust in two respects: First, the proposed money rule is based only on the information of period $t-1$. Hence, the rule is robust to any choice of the ordering of actions. Second, no information is needed on the stochastic process governing cost changes or velocity changes. This robustness relieves the central bank of the task of estimating the cost change process. The cost of using money as an information variable for expected cost changes and expected interest rates is that the some additional parameters must be known. These parameters are related to the 'money demand' parameters. We should emphasize that this kind of equilibrium exists only because of adjustment costs and it is not a general feature of a dynamic stochastic money-in-the-utility-function model combined with sticky prices.

Although central banks cannot possibly precisely control a wide monetary aggregate, they can easily control the monetary base[15]. It has been argued (see eg Goodhart 1994) that even controlling the monetary base is not only undesirable but also infeasible. The reason for this is the resulting increased volatility of interest rates. However, this is not a problem for central banks that use averaging of the required reserves. McCallum (1997) argues that 'neither interest rate nor monetary base instruments are infeasible,' and concludes that it is a question of desirability.

Our model exhibits the basic insight of Poole (1970): If there is uncertainty about the parameters of the 'money demand' function (money demand shocks in Poole's terminology), the interest rate is suitable as the monetary policy instrument. On the other hand, if productivity shocks occur or — in our setup — the parameters of the cost changes are not known, nominal money balances are a suitable monetary policy instrument. In this sense, our model shifts Poole's analysis from shocks to parameter uncertainty.

It is clear that the tradeoff between these two instrument choices is the parameter uncertainty concerning 'money demand', on the one hand, and parameter uncertainty concerning cost process, on the other hand. The third dimension is the issue of whether current or expected inflation is to be targeted — ultimately this is the issue of ordering decisions in our economy. It is clear that the choice of a monetary policy instrument is very much an empirical and economy-specific question.

[15]The money measure is not however restricted in this study.

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