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# Money as an indicator variable for monetary policy when money demand is forward looking

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The views expressed are those of the author and do not necessarily reflect the views of the Bank of Finland.

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# Money as an indicator variable for monetary policy when money demand is forward looking

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## Abstract

This paper studies the gain from using money as an indicator when monetary policy in made under data uncertainty. We use a forward and backward looking model, calibrated for the euro area. The policymaker cannot completely observe the state of the economy. Money reveals some of the private sector's information to the policymaker, especially if there is a forward looking element in money demand. We show that observing money can considerably reduce the loss that is due to incomplete information. However, taking also into account other financial market data could decrease the marginal importance of money as an indicator.


Key words: monetary policy, partial information, money, monetary aggregates, euro area

JEL classification numbers: E52, E58, E47

# Raha-aggregaatti indikaattorina rahapolitiikalle, kun rahan kysyntäyhtälö on eteenpäin katsova

Suomen Pankin keskustelualoitteita 9/2003

Lauri Kajanoja
Tutkimusosasto

## Tiivistelmä

Tässä tutkimuksessa tarkastellaan rahan määrän hyödyllisyyttä indikaattorina rahapolitiikan päätöksentekijän kannalta, kun taloudellisten muuttujien uusimpia arvoja ei täysin tunneta. Tutkimuksessa käytetään eteenpäin ja taaksepäin katsovaa makromallia, joka on kalibroitu euroalueen taloudelle. Rahapolitiikan päätöksentekijä ei havaitse talouden tilaa täydellisesti. Rahan määrä paljastaa rahapolitiikan päätöksentekijälle osan yksityisten taloudenpitäjien informaatiosta etenkin, jos rahan kysyntäyhtälössä on eteenpäin katsova elementti. Tutkimuksessa näytetään, että rahan käyttäminen indikaattorina voi vähentää huomattavasti sitä tappiota, jonka informaation epätäydellisyys taloudelle aiheuttaa. Muun rahoitusmarkkinainformaation huomioon ottaminen voisi kuitenkin vähentää rahan määrän merkitystä indikaattorina.

Avainsanat: rahapolitiikka, epätäydellinen informaatio, raha, raha-aggregaatit, euroalue

JEL-luokittelu: E52, E58, E47

# Contents

# 1 Introduction

The role of money in monetary policy has been subject to a large amount of debate. During the recent years, the debate has partly been motivated by the decision of the Eurosystem to give "a prominent role" for money in its monetary policy strategy, including a reference value for the growth rate of M3 monetary aggregate. It is a well established empirical fact that in the long run increases in the general price level tend to be related to increases in monetary aggregates. However, there is no agreement on the role of monetary aggregates in the actual process of monetary policy decision making, especially under relatively stable price developments.

Money often plays no explicit role in the model frameworks used in contemporary monetary policy analysis. Most notably, this is the case for nearly all applications of the New Keynesian modelling approach. However, some studies have identified effects which give a role for money. One possibility is to consider money as an indicator under "real time" data uncertainty. This paper quantitatively studies that effect.

Monetary policy is made in the environment of uncertainty. One source of uncertainty concerns the state of the economy. In terms of monetary policy analysis, the policymaker cannot observe the contemporaneous values of some essential variables, but only noisy signals of them. In theoretical terms, the most important missing piece of information is, arguably, an exact measure of the output gap.

This paper studies the value of monetary aggregates as indicator variables, assuming that the interest rate is used as the monetary policy instrument. We make quantitative assessments on the weakening effect that data uncertainty has on the performance of the economy, and on the improvement in the performance brought about by the optimal use of a monetary aggregate as an information variable. We use a New Keynesian model with added backward looking features, calibrated for the euro area economy. The value of the monetary aggregate as an information variable is increased by the existence of a forward looking element in the demand for money.

In the model setup of this paper, the policymaker cannot observe all relevant variables contemporaneously. Therefore, it has the motive for using a monetary aggregate as an additional indicator, when it filters the available information to update its perception on the state of the economy. The optimal way to filter the information is derived using the methodological framework suggested by Svensson & Woodford (2002b).

The paper is organized as follows. The model is given in Section 2, which also presents optimal monetary policy, given the policymaker's perception on the state of the economy. Section 3 presents the assumptions concerning the information available to the policymaker. Section 4 presents the results concerning the information value of money. Section 5 concludes.

## 2 Model

We use a New Keynesian model with added endogenous inflation and output persistence. The economy is described in the following equations.

$$y_t = \phi E_t y_{t+1} + (1-\phi)\, y_{t-1} - \eta\,(i_t - E_t \pi_{t+1}) + u_{1,t} \quad (2.1)$$

$$\pi_t = \beta\theta E_t \pi_{t+1} + (1-\theta)\,\pi_{t-1} + \gamma\,(y_t - y_t^n) + u_{2,t} \quad (2.2)$$

In the above equations, $\pi_t$ denotes the inflation rate and $i_t$ the nominal rate of interest. Symbols $y_t$ and $y_t^n$ denote (the logs of) output and potential output, respectively. Symbol $\beta$ denotes the discount factor, and $\phi$, $\eta$, $\theta$, and $\gamma$ denote other positive constants, with $\phi \in [0,1]$, and $\theta \in [0,1]$. The error terms $u_{1,t}$ and $u_{2,t}$ are i.i.d. They have zero means, and their variances are denoted by $\sigma_{u1}^2$ and $\sigma_{u2}^2$, respectively. Time periods are given in the subscripts, and $E_t$ is the expectations operator referring to the private agents' expectation formed in period $t$. The policymaker's expectations will not generally be identical to the private agents' expectations.

Equations (2.1) and (2.2) are, respectively, the aggregate demand function and the aggregate supply function. Together they form a model widely used in contemporary monetary policy analysis, see eg Rudebusch & Svensson (1999), Clarida, Gali & Gertler (1999), and Jensen (2002). When $\phi = 1$ and $\theta = 1$ the model is a version of the standard New Keynesian model, which is completely forward looking. It can be derived from explicit microfoundations, by linearizing a general equilibrium model with staggered price setting and monopolistic competition. The motivation for adding the lagged output and inflation terms in equations (2.1) and (2.2) is to improve the empirical performance of the model, as emphasized by eg Fuhrer & Moore (1995) and Fuhrer (1997, 2000). The theoretical justifications for adding these terms are rather vague, as discussed by eg Clarida, Gali & Gertler (1999, Section 6) and Jensen (2002).

Potential output is assumed to follow an exogenous process

$$y_t^n = \rho y_{t-1}^n + u_{3,t}, \quad (2.3)$$

where $\rho \in [0,1]$ is a constant, and $u_{3,t}$ is an i.i.d. stochastic error term with zero mean and variance denoted by $\sigma_{u3}^2$.

The time frequency of the model is here taken to be annual. Empirically plausible models for quarterly frequency typically have richer dynamics, and that would considerably complicate the analysis presented in the following sections of this paper. Since the model is taken to be annual, the short lags in monetary policy transmission implied by equations (2.1) and (2.2) are more plausible than would be the case under quarterly frequency.

The instrument of monetary policy is the interest rate. The policymaker sets $i_t$ in period $t$ so as to minimize, in a discretionary manner,

$$\sum_{j=0}^{\infty} \beta^j L_{t+j|t}, \quad (2.4)$$

where the period loss function is given by

$$L_t = \frac{1}{2}\left[\pi_t^2 + \lambda_y\,(y_t - y_t^n)^2 + \lambda_i\,(i_t - i_{t-1})^2\right]. \quad (2.5)$$

In the above equations, $\lambda_y$ and $\lambda_i$ denote positive constants. $L_{t+j|t}$ denotes the policymaker's expectations of $L_{t+j}$ as of period $t$.

Equation (2.4) is here taken as the society's loss function, following the customary approach in the literature. For a purely forward looking model, the above loss function with $\lambda_i = 0$ is derived from microfoundations to represent the (dis)utility of a representative consumer in eg Rotemberg & Woodford (1999). The interest rate smoothing objective, reflected in $\lambda_i > 0$, improves the empirical performance of the model in the sense that the variance of the interest rate would otherwise be implausibly large in model simulations, see eg Rudebusch & Svensson (1999).

## 2.1 Indicator variables

If we were to assume full information, the model would be completely defined in the above equations. However, we will assume data uncertainty, and therefore there will be room for a monetary aggregate as an indicator variable. We assume that the demand for money is given by the following equation. It includes a forward looking element.

$$m_t = \mu_1 m_{t-1} + \mu_2 E_t m_{t+1} + \mu_3 y_t - \mu_4 i_t + u_{4,t}, \tag{2.6}$$

where $m_t$ is defined as the log of the amount of money in real terms. Symbols $\mu_1$, $\mu_2$, $\mu_3$, and $\mu_4$ denote positive constants, and $u_{4,t}$ is an i.i.d. stochastic error term with zero mean and variance denoted by $\sigma^2_{u4}$.

The existence of a forward looking element in the money demand equation is not a very common assumption. However, it is suggested by eg Cuthbertson & Taylor (1987, 1990), Nelson (2002a, 2002b), and Ripatti (1998, Chapter 2). Also, several empirical money demand formulations include a feature which is consistent with the above model, namely, the dependence of money demand on long term interest rates.[1]

The money demand equation (2.6) can be derived assuming adjustment costs in money holdings, as shown in Appendix A. Even though explicitly forward looking formulations of empirical money demand equations are relatively rare, the idea of adjustment costs in money holdings is widely acknowledged and by no means new, see eg Goldfeld (1973). Empirical money demand models practically never imply immediate adjustment of money demand to a level given by the driving explanatory variables. To a large extent, this observed slow adjustment is seen to stem from the costs of adjusting money holdings. They are thought to arise from various costs related to portfolio adjustments, including the costs of the time and inconvenience in gathering and processing information.

Under rational expectations, the existence of adjustment costs directly implies a forward looking element in the money demand equation. Our baseline parameter values will satisfy $\mu_1 = \mu_2/\beta$, in accordance with the adjustment cost approach, as shown in Appendix A.

[1] To see that this feature is consistent with the current model, see equation (2.7) below, and remember the expectations theory on the term structure of interest rates.

In the formulation of Appendix A, the adjustment costs are assumed to be related to changes in money holdings in real terms, not in nominal terms, as in some other studies. In this respect, our approach follows that of Cuthbertson & Taylor (1990) and Nelson (2002a, b), among others. Both formulations have their merits, theoretically as well as empirically. Our choice is motivated by a consideration of the source of the adjustment costs. Costs related to information probably dominate direct transaction costs, when it comes to the costs of adjusting money holdings by individual households and firms.

Adjustment costs is not the only argument that can be presented for the existence of a forward looking element in money demand. It is an old perception that the demand for real balances can be affected by current wealth, and not just by current income. For example, Friedman (1956) includes income in a money demand equation just as a proxy for wealth. If it is the case that wealth affects money demand, then it is obvious that one should include a forward looking element in a money demand function, if the driving variables are income and the interest rate, as in equation (2.6). This is because current wealth naturally depends on the expected future values of the driving variables.

In addition to adjustment costs, a case for the existence of a forward looking element in money demand can be made also out of different arguments.

When interpreting some results presented in the following sections, it is useful to note that equation (2.6) implies

$$m_t = \chi_1 m_{t-1} + \frac{1}{\chi_2} E_t \left[ \widetilde{m}_t + \frac{1}{\chi_2} \widetilde{m}_{t+1} + \left( \frac{1}{\chi_2} \right)^2 \widetilde{m}_{t+2} + ... \right], \tag{2.7}$$

where $\widetilde{m}_t \equiv \mu_3 y_t - \mu_4 i_t + u_{4,t}$. Equation (2.7) presents the standard forward-backward looking solution to the second order difference equation (2.6). For plausible parameter values, one of the characteristic roots of the equation is between zero and one, and the other is greater than one. Here, the roots are denoted by $\chi_1 \in (0, 1)$ and $\chi_2 \in (1, \infty)$. According to equation (2.7), current real money demand depends on the expected future values of output and the interest rate, as well as on their past values through $m_{t-1}$.

The informational assumptions used in this paper will not be described at full until in Section 3. Let us, however, present here the policymaker's noisy observation concerning contemporaneous output. As is well known, sizable revisions are often made to GDP statistics, even several quarters after their initial publication. The following equation describes the implications of such revisions. The policymaker's period $t$ observation on same period output is given by

$$y_t^0 = y_t + w_t \tag{2.8}$$

where $w_t$ is an i.i.d. stochastic error term with zero mean and variance denoted by $\sigma_w^2$. While the observation on the same year output is noisy, it will be assumed that the policymaker learns the true value of $y_t$ in year $t + 1$. The value of $\sigma_w^2$ used in the simulations is based on the study by Coenen, Levin & Wieland (2001), and it is calculated using the actual revisions that have taken place in the euro area GDP statistics.

## 2.2 Parameter values

The values of the parameters that appear in the above equations are chosen so as to represent "compromise values" of the literature. The variances for key variables that the parameters produce in the simulations are reasonably close to those observed in the data. The baseline values are presented in Table 1. When considering them, one should keep in mind that here the time frequency is taken to be annual rather than quarterly, as in several other papers.

Variables $y_t^n$, $y_t$, $y_t^0$, and $m_t$, are defined as percentage deviations from the steady state values, which can be assumed to vary over time. Variables $i_t$ and $\pi_t$ are defined as percentage point deviations form the steady state values. Therefore, no constant terms appear in equations (2.1), (2.2), (2.3), or (2.6). Consequently, for example, the inflation variable $\pi_t$ can be defined as a deviation of some target value reached in the steady state.

| $\phi$ | $\theta$ | $\eta$ | $\gamma$ | $\beta$ | $\rho$ | $\lambda_y$ | $\lambda_i$ | |
|---|---|---|---|---|---|---|---|---|
| 0.56 | 0.52 | 0.06 | 0.18 | 0.96 | 0.95 | 1 | 0.1 | |
| $\mu_1$ | $\mu_2$ | $\mu_3$ | $\mu_4$ | $\sigma_w$ | $\sigma_{u1}$ | $\sigma_{u2}$ | $\sigma_{u3}$ | $\sigma_{u4}$ |
| 0.38 | 0.37 | 0.25 | 0.13 | 0.24 | 0.79 | 0.65 | 0.36 | $0.25, 0.12$ |

Table 1: Baseline parameter values.

The values of the parameters in equations (2.1), (2.2), (2.3), (2.5), and (2.8) are similar to those used by Ehrmann & Smets (2001) for the euro area, except for the appearance of $\beta$ in equation (2.2). The parameters of the money demand equation are chosen so that in the long run they imply unit scale elasticity and an interest rate semielasticity of 0.5. These are conventional values. The parameters that determine the dynamics of the money demand equation, $\mu_1$ and $\mu_2$, are set according to the values estimated and used by Nelson (2002a, b).[2] The baseline values satisfy $\mu_1 = \mu_2/\beta$, as discussed in Section 2.1 and Appendix A. Using the estimates of Cuthbertson & Taylor (1987, 1990) would result in somewhat greater values for $\mu_1$ and $\mu_2$ than those given in Table 1.

What remains to be described is the choice of the value for the parameter that is the most critical one for the results of this study, that is, the money demand shock standard error $\sigma_{u4}$. Here, most of the results are presented for the two different values presented in Table 1. In choosing $\sigma_{u4}$ one can use empirical money demand studies as a point of reference.[3] For $\sigma_{u4}$ concerning annual euro area M3, they imply a range of 0.12 through 0.25. Since these are in-sample estimates, a value close to 0.25 seems to be a good candidate.

[2] Nelson uses quarterly frequency. We infer Nelson's value for parameter $\xi$, which appears in Appendix A, and then use that value to calculate $\mu_1$ and $\mu_2$ for annual frequency.

[3] The empirical studies used as references here are Brand & Cassola (2000), Brüggeman (2000), Calza, Gerdermeier & Levy (2001), Coenen & Vega (1999), Dedola, Gaiotti & Silipo (2001), Gerlach & Svensson (2002), and earlier studies surveyed by Browne, Fagan & Henry (1997).

However, to see the largest plausible information value of $m_t$ in the current context, we consider the case of $\sigma_{u4} = 0.12$, in addition to $\sigma_{u4} = 0.25$.[4]

To check robustness, we experiment with a large scale of non-baseline parameter values for every parameter of the model. This will be done in Figures 4 and 5.

## 2.3 Optimal monetary policy

The policymaker sets the interest rate in period $t$ so as to minimize the loss presented in equation (2.4). We consider optimal time-consistent policy, meaning that the policymaker re-optimizes each period, taking the private sector expectations as given.

Svensson & Woodford (2002b) show that the so called certainty equivalence result holds in this setup, even though the policymaker does not have complete information on the state of the economy, and even though the information structure is asymmetric. The certainty equivalence means that the optimal policy is the same as if the state of the economy were fully observable, except that the policymaker now responds to the optimal estimate of the state of the economy rather than to the actual state. This means that the optimal discretionary monetary policy can be represented by a reaction function which gives $i_t$ as a linear combination of the state variables of the model, as they are perceived by the policymaker. Certainty equivalence implies that the only parameters that affect the optimal monetary policy as presented in equation (2.10) below, are $\phi$, $\theta$, $\eta$, $\gamma$, $\beta$, and $\rho$.

The model is presented in a state-space form in Appendix B. There, the vector of state variables is defined as

$$X_t = \begin{bmatrix} y_{t-1} & \pi_{t-1} & y_t^n & u_{1,t} & u_{2,t} & i_{t-1} & m_{t-1} & u_{4,t} \end{bmatrix}'. \tag{2.9}$$

The optimal discretionary monetary policy reaction function is derived using the algorithm described in Svensson & Woodford (2002b, Appendix A). One can write the optimal policy in terms of a vector $F$ as

$$\begin{aligned} i_t &= FX_{t|t} \\ &= 1.01y_{t-1|t} + 0.67\pi_{t-1|t} - 1.10y_{t|t}^n + 2.29u_{1,t|t} \\ &+ 1.39u_{2,t|t} + 0.45i_{t-1|t}, \end{aligned} \tag{2.10}$$

where $y_{s|t}$ denotes the policymaker's period $t$ perception of $y_s$, and similarly for all other variables. Note that the only state variables that do not enter

[4]The empirical models of euro area M3 considered here use quarterly data. The estimate for quarterly $\sigma_{u4}$ is transformed to annual frequency taking the annual error as an average of the quarterly errors, and assuming that the quarterly errors are serially uncorrelated. The latter assumption means that the endpoints of the range for annual $\sigma_{u4}$ should probably be slightly greater than the 0.12 and 0.25 given in the text. In addition, one should note that the values of $\sigma_{u4}$ considered here need not be plausible for other monetary aggregates or other countries. Indeed, in other simulation studies with money demand equations, values considerably greater than one are typically used for $\sigma_{u4}$, when transformed into annual frequency.

the reaction function are the last two elements of vector $X_t$, that is, those associated with money demand. This is due to the certainty equivalence.

The reaction function given in equation (2.10) has standard properties for a New Keynesian model with added backward looking features. The policymaker raises the interest rate in response to a perception that there has been a positive aggregate demand shock or a positive cost-push shock. This is reflected in the coefficients of $u_{1,t|t}$ and $u_{2,t|t}$. Lagged output and inflation affect the interest rate because of the lagged terms in equations (2.1) and (2.2). If potential output $y_t^n$ is increased, according to the policymaker's perception, it will lower the interest rate, since now there is more room for production to increase without an increase in inflation.[5] The last term of equation (2.10) follows from the interest rate smoothing motive assumed in equation (2.5).

# 3 Information

In this section, we describe the information sets that the agents are assumed to have. We then show how that information is optimally filtered, using the methodological framework developed by Svensson & Woodford (2002a, b, c, 2003) in a series of papers. They build on the work by Pearlman, Currie & Levine (1986) and Pearlman (1992), among others. Previous applications of the framework include Aoki (2001, 2002), Coenen, Levin & Wieland (2001), Ehrmann & Smets (2001), Dotsey & Hornstein (2002), and Nelson (2002b).

The form of the model and the parameter values are assumed to be known to everybody. In contrast, the values of all variables are not always known to the central bank.

## 3.1 Informational assumptions

The model setup of this paper is analyzed under three different sets of informational assumptions. They are described below. The first case is one where the policymaker and the private agents have the same information set. In contrast, information is asymmetric in the latter two cases. In the last case, two different values will be used for the money demand error term variance $\sigma_{u4}^2$.

**Complete information.** In period $t$, both the policymaker and the private agents observe the complete state variable vector $X_s$ for all $s \leq t$. Equivalently, one can assume that in period $t$ they observe the variable set $\{y_t^n, y_t, \pi_t, m_t\}$ and all its earlier values, because observing this set of variables gives them enough information so that they can infer $X_s$ for all $s \leq t$.

[5] It can be noted that the coefficient of $y_{t|t}^n$ would be zero under a New Keynesian model setup with $\phi = \theta = 0$ and $\rho = 1$, since output would immediately adjust to a change in its potential level without an interest rate reaction.

**Incomplete information, money not observed.** In period $t$ the policymaker observes $\{y_{t-1}, y_t^0, \pi_t\}$. It also knows all earlier values of these variables or, equivalently, it remembers its own previous estimates $X_{s|t-1}$ for all $s \leq t$. The private agents again observe $X_s$ for all $s \leq t$.

**Incomplete information, money observed.** In period $t$ the policymaker observes $\{y_{t-1}, y_t^0, \pi_t, m_t\}$ and also remembers $X_{s|t-1}$ for all $s \leq t$. The private agents again observe $X_s$ for all $s \leq t$. In this case, results will be presented for two different assumptions concerning the money demand error term variance $\sigma_{u4}^2$. For these values, see Table 1.

## 3.2 Filtering of information

Denoting the observation vector by $Z_t$, the filtering equations can be written as

$$X_{t|t} = \Phi X_{t|t-1} + \Psi Z_t \tag{3.1}$$

where $\Phi$ and $\Psi$ are matrices with the appropriate dimensions.

To find out the optimal $\Phi$ and $\Psi$, we apply the framework of Svensson and Woodford (2002b). Appendix B presents the derivation of the optimal $\Phi$ and $\Psi$ in terms of the parameters of the model.

Using the optimal filter, one can express the interest rate directly as a function of the policymaker's observations. According to equation (2.10), the optimal policy can be written as $i_t = FX_{t|t}$. The optimal filtering process of equation (3.1) can, in turn, also be written as $X_{t|t} = \Gamma X_{t-1|t-1} + \Psi Z_t$ where $\Gamma$ is a matrix with the appropriate dimensions, see Appendix B. Iterating forward the latter equation, the interest rate can be written as

$$i_t = \sum_{j=0}^{\infty} F\Gamma^j \Psi L^j Z_t \tag{3.2}$$

where $L$ is the lag operator. The long run effects of the observations on $i_t$ can be found by setting $L = 0$ in equation (3.2).

### 3.2.1 The case where money is observed

As an example, let us consider some features of the optimal filter in the case where the policymaker has incomplete information but observes money, and $\sigma_{u4} = 0.25$.

The observation vector of the policymaker is

$$Z_t = \begin{bmatrix} y_{t-1} & y_t^0 & \pi_t & m_t \end{bmatrix}'. \tag{3.3}$$

The optimal filter is given by equation (3.1) where

$$\Psi = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ -0.036 & 0.130 & 0.013 & 0.501 \\ -0.397 & 0.777 & 0.195 & -0.093 \\ -0.016 & -0.186 & 0.678 & 0.085 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0.020 & -0.011 & 0.285 & 0.589 \end{bmatrix}, \tag{3.4}$$

and the corresponding matrix $\Phi$ is presented in equation (B2.16) of Appendix B.2.

The last column of the above matrix $\Psi$ presents the coefficients of the observed real balances $m_t$ in the optimal filtering equations. Note that the greater is $m_t$ the greater is $y^n_{t|t}$, as the corresponding coefficient equals $[\Psi]_{3,4} = 0.501 > 0$. The fourth column of $\Psi$ is obviously absent in the case where money is not observed. However, the existence of the fourth column of $\Psi$ is not the only difference between these two cases. Obviously, adding money in the set of observable variables also changes the elements in the first three columns of $\Psi$.

Let us now consider the optimal interest rate expresses directly in terms of the policymaker's observations. For some set of constants $\{a_{1,j}, a_{2,j}, a_{3,j}, a_{4,j}\}_{j=0}^{\infty}$, equation (3.2) can now be written as

$$i_t = \sum_{j=0}^{\infty} a_{1,j} y_{t-1-j} + \sum_{j=0}^{\infty} a_{2,j} y^0_{t-j} + \sum_{j=0}^{\infty} a_{3,j} \pi_{t-j} + \sum_{j=0}^{\infty} a_{4,j} m_{t-j}, \tag{3.5}$$

where

$$\sum_{j=0}^{\infty} a_{1,j} = 0.33, \ \sum_{j=0}^{\infty} a_{2,j} = 1.48, \ \sum_{j=0}^{\infty} a_{3,j} = 1.21, \ \text{and} \ \sum_{j=0}^{\infty} a_{4,j} = -1.67.$$

The latter expressions give us the long run effects of observations $y_{t-1}$, $y^0_t$, $\pi_t$ and $m_t$ on the interest rate. The corresponding same period effects are $a_{1,0} = 0.12$, $a_{2,0} = 1.38$, $a_{3,0} = 1.38$, and $a_{4,0} = -0.65$. The negative effect of real balances on the interest rate follows from the fact that money is an indicator of potential output, as seen in equation (3.4). The same period effect of money on the interest rate is only $-0.65$, while the long run effect is $-1.67$. This reflects the fact that the policymaker cannot exactly identify the source of the latest change in real balances. They are not only affected by potential output shocks but also by aggregate demand shocks, among other things.

The fact that the amount of money in real terms is a valuable indicator of potential output results from the form of the money demand equation. This can be seen by considering equation (2.7), noting that current money demand is affected by the private agents' expectations concerning future output. Remember that under the current assumptions the private agents observe the contemporaneous potential output, but the policymaker does not.

Also remember the strong persistence in potential output. The private agents know that the policymaker will over time learn about the true value of potential output and act so as to bring output close to potential. Therefore, the policymaker can learn about period $t$ potential output by considering period $t$ demand for money.

# 4 Value of money as an indicator

Table 2 presents the economic outcome under four different informational assumptions. The values reported in the table are based on simulations. They are the mean values over 1000 replications, with each being a sample of 500 years. In each replication, the model was simulated for 600 years, and the first 100 years were ignored in order to abstract from the start-up departures from steady state conditions. The same sets of shock series created by a random number generator were used for all the informational assumptions.

| **Information** (I=incomplete) | **Std of MD shock** | **Mean loss** (Index, complete information = 100) | **Var of output gap** | **Var of infla-tion** | **Var of int.rate change** |
|---|---|---|---|---|---|
| Complete | | 100 | 0.992 | 1.364 | 5.513 |
| I, no money | | 110 | 1.290 | 1.334 | 5.717 |
| I, money | 0.25 | 108 | 1.237 | 1.350 | 5.612 |
| I, money | 0.12 | 106 | 1.160 | 1.364 | 5.480 |

Table 2: Economic outcomes.

As shown by Table 2, the more information the policymaker has, the better is the performance of the economy. For each assumption concerning $\lambda_y$ and $\lambda_i$, the economy performs best in the case of complete information. The worst performance takes place in a situation where the policymaker cannot directly observe $y_t$ or $y_t^n$, and does not use the monetary aggregate as an additional piece of information. Using money as an indicator improves the performance of the economy. The smaller is the money demand error term variance $\sigma_{u4}^2$ the greater is the improvement.

The fact that more information improves the performance of the economy is the result of better monetary policy. The faster the policymaker learns the shocks that hit the economy, the closer to optimal are the policy reactions to those shocks.

In addition to Table 2, the properties of the model under different informational assumptions can be studied by considering the effects of particular shocks. Figures 1 through 3 show the dynamic responses of the economy to one standard deviation innovations in the shock terms.

Figure 1 presents impulse responses showing four cases in each figure. The three cases are 1) complete information, 2) incomplete information with money not observed, 3) incomplete information with money observed and $\sigma_{u4} = 0.25$, and 4) incomplete information with money observed and $\sigma_{u4} = 0.12$. The less the policymaker has information, the stronger tend to be the reactions of the output gap and the inflation rate to the shocks in $u_{1,t}$, $u_{2,t}$, and $u_{3,t}$. This is because with less information the interest rate reactions tend to be further away from optimal. However, additional information can also lead to a worse outcome in the case of some particular shocks, as shown in the response of the economy to an output observation shock.

Figure 2 presents the actual impulse response and the responses as contemporarily perceived by the policymaker. All lines in all graphs correspond to the information assumption case number 3 of the previous paragraph. That is, we study the case where information is incomplete but money is observed, with the standard deviation of the money demand error term being $\sigma_{u4} = 0.25$. The graphs in the third column present the responses of inflation and the interest rate, which are contemporaneously known to the policymaker. The first column of Figure 2 shows how fast the policymaker learns the true value of the output gap, when the economy faces different shocks. Since here it is assumed that money is used as an indicator, a shock in the money demand function is shown to lead to a mistaken response by the policymaker. Under complete information, the policymaker naturally does not react to such a shock, as shown in Figure 1.

Figure 3 shows the errors of the policymaker in its contemporaneous perceptions concerning $y_t^n$ and $y_t$. In each figure the perception error is presented for three cases: 1) incomplete information with money not observed, 2) incomplete information with money observed, assuming $\sigma_{u4} = 0.25$, and 3) the same as the previous case except that $\sigma_{u4} = 0.12$. An error above zero means that the policymaker's perception of the variable is greater than the true value. For example, the first graph in the first column shows how much faster the policymaker learns the true value of a potential output shock if it uses monetary aggregate as an indicator.

## 4.1 Robustness of the information value of money

Figure 4 studies the robustness of the results to different parameter values. In Figure 4 each graph depicts, for various values of one parameter, the effect of observing money on the expected discounted losses of equation (2.4).[6] What is shown is how much, in percentage terms, money reduces the loss that is caused by the incompleteness of information. A reduction of 100% would mean that using money as an indicator leads to complete information. That is, the graphs depict $100 \cdot (L_{II} - L_{IIM})/(L_{II} - L_{CI})$, where $L_{CI}$ denotes the value of equation (2.4) under complete information, $L_{II}$ the corresponding loss under incomplete information without money, and $L_{IIM}$ under incomplete information with money observed.

[6] The value of equation (2.4) can be calculated as in Ehrmann & Smets (2001, Appendix A.3), with small modifications due to the assumption of asymmetric information. The modifications concern the term which they denote by $Ch^2$.

Figure 4 looks at one parameter at a time, setting the rest at their baseline values, with $\sigma_{u4} = 0.25$. The vertical dashed line displays the baseline value. The graphs are in the following order: $\beta$, $\phi$, $\gamma$, $\theta$, $\eta$, $\sigma_{u1}$, $\sigma_{u2}$, $\sigma_{u3}$, $\sigma_w$, $\rho$, $\mu_1 = \mu_2/\beta$, $\mu_3/(1-\mu_1-\mu_2)$, $\mu_4/(1-\mu_1-\mu_2)$, $\sigma_{u4}$, $\lambda_y$, $\lambda_i$. Among these, $\mu_3/(1-\mu_1-\mu_2)$ is the long run scale elasticity of money demand, and $\mu_4/(1-\mu_1-\mu_2)$ is the long run interest rate semi elasticity of money demand.

As Figure 4 shows, the size of the improvement in the performance of the economy brought about by using money as an indicator seems to be fairly robust to changes in the model parameters. In this respect, the parameter value that is the most crucial is that of $\sigma_{u4}$, as noted above. The choice of $\sigma_{u4}$ was discussed in detail in Section 2.2.

The dynamics of money demand are also crucial to the results. The effect of changing the value of $\mu_1 = \mu_2/\beta$ is shown in Figure 4, third row, third column. Under the baseline $\mu_1$ and $\mu_2$, the current values of the driving variables have a weight of $1-\mu_1-\mu_2 = 0.25$ in equation (2.6). At the left end of the graph $\mu_1 = \mu_2/\beta = 0$, meaning that money demand equation is of a static form. Such a form is frequently used in simplified models, even though it is not empirically plausible. If $\mu_1 = \mu_2/\beta = 0$ the value of money as an indicator is practically zero. The reason for this was discussed at the end of Section 3.2.1: it is the lead term in the demand for money that makes money an indicator of potential output.

To see the importance of the forward looking element in money demand, let us study what happens if $\mu_2$ changes relative to $\mu_1$. So far, including Figure 4, we have assumed that $\mu_1 = \mu_2/\beta$. This is not the case in Figure 5. Here, in order not to change the long run coefficients of $y_t$ and $i_t$ when we change $\mu_2$, we set $\mu_1 = \mu_1^* + \mu_2^*/\beta - \mu_2/\beta$, where $\mu_1^*$ and $\mu_2^*$ denote the baseline values. According to Figure 5, the value of $\mu_2$ has a strong effect on the gain from observing money. At the left end of Figure 5 the money demand equation is purely backward looking, with $\mu_2 = 0$ and $\mu_1 = 0.75$. As in the case of static money demand, the information value of money is now close to zero.

In addition to $\mu_2 > 0$, another crucial assumption concerning the value of money as indicator is that the private agents possess some information not known to the policymaker. If we change the setup by assuming symmetric information, money is no longer an important piece of information to the policymaker. Such an assumption would mean that the set of variables that the private agents observe is identical to the one observed by the policymaker, described in Section 3.1.

In this paper, monetary policy is assumed to be discretionary, and assuming commitment could make a difference. However, the results of Ehrman & Smets (2001) within a roughly similar model framework are fairly robust to a change in this assumption, suggesting that the same could be true here.

The results of this study can be compared to those of Coenen, Levin & Wieland (2001), Dotsey & Hornstein (2002) and Nelson (2002b), who also study the role of a monetary aggregate as an indicator, assuming that the policymaker does not have complete information. The value of money as an indicator is found to be fairly small in the former two studies, reflecting the fact that money demand equation is not forward looking as it is in this study. Also, the private agents' information set does not include anything that the policymaker does not directly observe. Nelson (2002b) uses a model framework that has many of the same basic features as this study. However, he does not comprehensively report the results concerning the information value of money. Given that he assumes a considerably larger variance for the money demand error term, money is not likely to be as a valuable indicator for the policymaker in his setup as it turns out to be here.

Concerning the interpretation of the results of this study, recall that the larger is the monetary aggregate, the lower should the interest rate be, as shown in equation (3.5). This would seem to be in contradiction with the way central banks typically interpret monetary aggregates as indicators of future inflationary pressures. However, one should note that this result only refers to the information value of the monetary variable in addition to all other information that the policymaker has, including the rate of inflation. The result only holds for the stock of money in real terms, not in nominal terms. Nominal money growth can be positively correlated with inflation. What the model framework implies is that if real balances are larger than predicted by standard backward looking money demand equations, this is a possible indication of an increase in potential output. Such a conclusion naturally depends on the assumption that the policymaker does not think that the private agents are making a mistake in their current assessment of potential output.

# 5 Conclusions

This paper presents a quantitative assessment on the usefulness of money as an indicator of the state of the economy, when monetary policy is considered. We use a backward-forward looking model, calibrated for the euro area economy. The model and its parameters are assumed to be perfectly known, but the values of some variables are not. The policymaker does not have complete information on the state of the economy. We use the framework of Svensson and Woodford (2002b) to find out how the policymaker optimally filters the information it receives.

If the policymaker has less than complete information, the economy performs considerably worse than under full information. This is because of sub-optimal monetary policy reactions, resulting from the fact that the policymaker only slowly learns about the shocks that hit the economy. Using money as an indicator considerably improves the performance of the economy. If the variance of the money demand error term is relatively small, observing money can eliminate more than one third of the loss that stems from incomplete information.

Regarding the results, an important assumption is that the private agents possess information which the policymaker cannot directly observe. Another important feature of the model is the forward looking nature of the money demand equation. Without these features, the value of money as an indicator variable turns out to be very small. However, the core results concerning the value of money as an indicator are fairly robust to other changes in the parameters of the model.

The information value of money in this framework largely stems from the fact that the demand for real balances is affected by the private agents' information concerning potential output. If the policymaker observes the growth in real balances being greater than that predicted by a standard backward looking money demand equation, the policymaker revises upward its estimate of potential output. This means that faster output growth looks to be possible without increased inflationary pressures, leading a lower interest rate under optimal monetary policy. Such a policy response to money growth can be seen as unconventional. Naturally, the inference by the policymaker follows from the assumption that the policymaker thinks that the private agents are making a correct assessment on the latest developments in potential output.

In this study we quantify one possible role that money can play in monetary policy. We look at money as an indicator, we focus on the case where money only matters through the money demand equation, and we deal with a fairly limited set of observable variables. Obviously, the value of money as an indicator depends on the existence of other possible sources of information. In practice, central banks observe a large number of indicators. It is likely that some indicators not taken into account in this study reveal pieces of the same information as money. A lot of research remains to be done on the optimal use of money as an indicator when analyzed in combination with other indicators, especially other financial market data. It would seem that the analysis concerning money is ideally done as a part of an analysis concerning also equity prices, bond yields, and credit, among other things.

# A Appendix: Demand for money

The form of the money demand equation (2.6) can be motivated by assuming that there are quadratic adjustment costs in money holdings in real terms. Assume that a private agent sets her demand for money so as to minimize

$$\sum_{j=0}^{\infty} \beta^j \Lambda_{t+j|t} \tag{A1.1}$$

with periodic loss

$$\Lambda_t = (m_t - m_t^*)^2 + \xi (m_t - m_{t-1})^2 \tag{A1.2}$$

where

$$m_t^* = \varphi_y y_t - \varphi_i i_t + \varsigma_t, \tag{A1.3}$$

In equation (A1.3), $\varphi_y$ and $\varphi_i$ denote positive constants, and $\varsigma_t$ is an i.i.d. mean zero shock. It is straightforward to show that equation (2.6) follows from this maximization problem, when $\mu_3 = \varphi_y \kappa$, $\mu_4 = \varphi_i \kappa$, $\mu_1 = \xi\kappa$, $\mu_2 = \beta\xi\kappa$, and $u_{4,t} = \varsigma_t \kappa$, where $\kappa \equiv \frac{1}{1+\xi+\beta\xi}$.

Equation (A1.3) has the form of a standard long run money demand function. The values of $\mu_3$ and $\mu_4$ of equation (2.6) that appear in Table 1 are set so as to imply $\varphi_y = 1$ and $\varphi_i = 0.5$.

# B Appendix: Filtering

This appendix shows how the policymaker optimally uses the information it has to form a perception on the state of the economy. First, the model is presented in a state-space form.

## B.1 Model in state-space form

The model of Section 2 can be written in state-space form as

$$\begin{bmatrix} X_{t+1} \\ \Omega E_t x_{t+1} \end{bmatrix} = A \begin{bmatrix} X_t \\ x_t \end{bmatrix} + B i_t + \begin{bmatrix} u_{t+1} \\ 0 \end{bmatrix}, \tag{B1.1}$$

where $X_t$ is the vector of predetermined variables, defined as

$$X_t = \begin{bmatrix} y_{t-1} & \pi_{t-1} & y_t^n & u_{1,t} & u_{2,t} & i_{t-1} & m_{t-1} & u_{4,t} \end{bmatrix}' \tag{B1.2}$$

$x_t$ is the vector of forward-looking variables, defined as

$$x_t = \begin{bmatrix} y_t & \pi_t & m_t \end{bmatrix}', \tag{B1.3}$$

and $u_t$ is the following vector of error terms.

$$u_t = \begin{bmatrix} 0 & 0 & u_{3,t} & u_{1,t} & u_{2,t} & 0 & 0 & u_{4,t} \end{bmatrix}'. \tag{B1.4}$$

The matrices that appear in equation B1.1 can be written as

$$A = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & \rho & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -(1-\phi) & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & -(1-\theta) & \gamma & 0 & -1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -\mu_1 & -1 & -\mu_3 & 0 & 1 \end{bmatrix}, \tag{B1.5}$$

$$\Omega = \begin{bmatrix} \phi & \eta & 0 \\ 0 & \beta\theta & 0 \\ 0 & 0 & -\mu_2 \end{bmatrix}, \tag{B1.6}$$

and

$$B = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & \eta & 0 & \mu_4 \end{bmatrix}'. \tag{B1.7}$$

Equation (2.5) can be written as

$$L_t = Y_t' W Y_t, \tag{B1.8}$$

where

$$W = \begin{bmatrix} \lambda_y & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & \lambda_i \end{bmatrix} \tag{B1.9}$$

and

$$Y_t = C \begin{bmatrix} X_t \\ x_t \end{bmatrix} + C_i i_t, \tag{B1.10}$$

where

$$C = \begin{bmatrix} 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{B1.11}$$

and

$$C_i = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix}'. \tag{B1.12}$$

As an example of an observation vector, let us present $Z_t$ of Section 3.2.1. It is $Z_t = \begin{bmatrix} y_{t-1} & y_t^0 & \pi_t & m_t \end{bmatrix}'$ and can be written as follows.[7]

$$Z_t = D \begin{bmatrix} X_t \\ x_t \end{bmatrix} + v_t, \tag{B1.13}$$

where

$$v_t = \begin{bmatrix} 0 & w_t & 0 & 0 \end{bmatrix}' \tag{B1.14}$$

and

$$D = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}. \tag{B1.15}$$

## B.2 Optimal filter

This section follows Svensson & Woodford (2002b). It describes how matrices $\Phi$ and $\Psi$ can be derived, when the parameters of the model are known.

As in equation (2.10), the optimal monetary policy can be described as

$$i_t = FX_{t|t}. \tag{B2.1}$$

where $F$ is the vector given in equation (2.10). In addition, the policymaker's estimate of the forward looking variables of the model can be written as

$$x_{t|t} = GX_{t|t}. \tag{B2.2}$$

[7] $Z_t$ could also be defined to include lags of $y_{t-1}$, $y_t^0$, $\pi_t$, and $m_t$. In that case, the inverse operators in equations (B2.13) and (B2.14) are defined as a generalized inverses.

where $G$ is a matrix of the appropriate dimensions. The same algorithm that is used to solve for $F$ also yields $G$. The actual $x_t$ depends not only on the state of the economy $X_t$ but also on the policymaker's estimate of it. One can write

$$x_t = G^1 X_t + \left(G - G^1\right) X_{t|t}, \tag{B2.3}$$

for matrix $G^1$ to be determined.

Equations (B1.1), (B1.13), (B2.1), and (B2.3) imply that

$$X_{t+1} = HX_t + JX_{t|t} + u_{t+1}, \tag{B2.4}$$
$$Z_t = LX_t + MX_{t|t} + v_t, \tag{B2.5}$$

where

$$H \equiv A_{11} + A_{12}G^1, \tag{B2.6}$$
$$J \equiv B_1 F + A_{12}\left(G - G^1\right), \tag{B2.7}$$
$$L \equiv D_1 + D_2 G^1, \tag{B2.8}$$
$$M \equiv D_2\left(G - G^1\right), \tag{B2.9}$$

where we use the following decompositions of matrices $A$, $B$, and $D$, made according to $X_t$ and $x_t$.

$$A = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}, B = \begin{bmatrix} B_1 & B_2 \end{bmatrix}, D = \begin{bmatrix} D_1 & D_2 \end{bmatrix}. \tag{B2.10}$$

Svensson & Woodford (2002b) show that the optimal matrices $\Phi$ and $\Psi$ of equation (3.1) can be written as

$$\Phi = (I + KM)^{-1}(I - KL) \tag{B2.11}$$
$$\Psi = (I + KM)^{-1} K, \tag{B2.12}$$

where $K$ and $P$ are defined as follows.

$$K = PL'\left(LPL' + \Sigma_2\right)^{-1}, \tag{B2.13}$$

where $\Sigma_2 \equiv cov\,(v_t)$, and $P \equiv cov\left(X_t - X_{t|t-1}\right)$, satisfying

$$P = H\left[P - PL'\left(LPL' + \Sigma_2\right)^{-1} LP\right] H' + \Sigma_1, \tag{B2.14}$$

where $\Sigma_1 \equiv cov\,(u_t)$. Using equation (B2.4), matrix $\Gamma$ that appears in equation (3.2) can be written as $\Phi\,(H + J)$.

Finally, it can be shown that matrix $G^1$ satisfies

$$G^1 = A_{22}^{-1}\left\{-A_{21} + \Omega\left[G^1 + \left(G - G^1\right) KL\right] H\right\}. \tag{B2.15}$$

The numerical calculations required to solve for $\Phi$ and $\Psi$ are made more complicated by the fact that the matrices $H$, $L$, $K$, $P$, and $G^1$ are determined simultaneously by the system of equations (B2.6), (B2.8), (B2.13), (B2.14), and (B2.15), part of which are non-linear.

An example of matrix $\Psi$ is given in equation (3.4) in Section 3.2.1. It shows the optimal $\Psi$ in the case of incomplete information, when money is observed and $\sigma_{u4} = 0.25$. The corresponding optimal $\Phi$ can be shown to be

$$\Phi = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.017 & 0.116 & 0.625 & -0.045 & 0.241 & 0.057 & -0.230 & -0.602 \\ -0.008 & -0.070 & -0.297 & 0.080 & -0.145 & 0.042 & 0.043 & 0.112 \\ 0.004 & -0.448 & 0.153 & -0.026 & 0.067 & 0.020 & -0.039 & -0.103 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ -0.009 & -0.059 & -0.314 & 0.026 & -0.123 & 0.067 & -0.271 & 0.291 \end{bmatrix}. \tag{B2.16}$$

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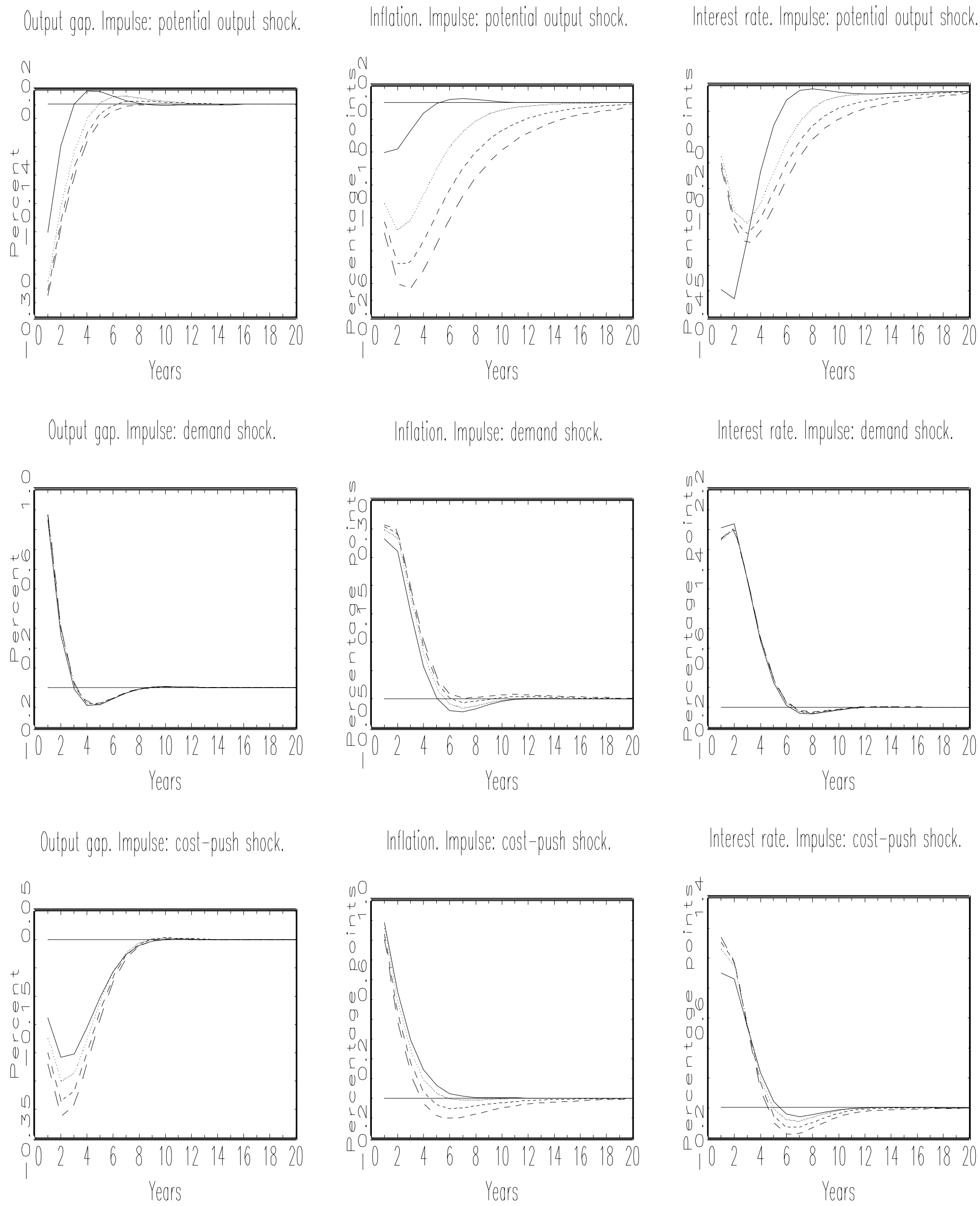


Figure 1: Actual impulse responses.
Solid line: complete information. Dashed line: incomplete information, without money. Short dashes: incomplete information, with money, std(MD)=0.25. Dotted line: incomplete information, with money, std(MD)=0.12.

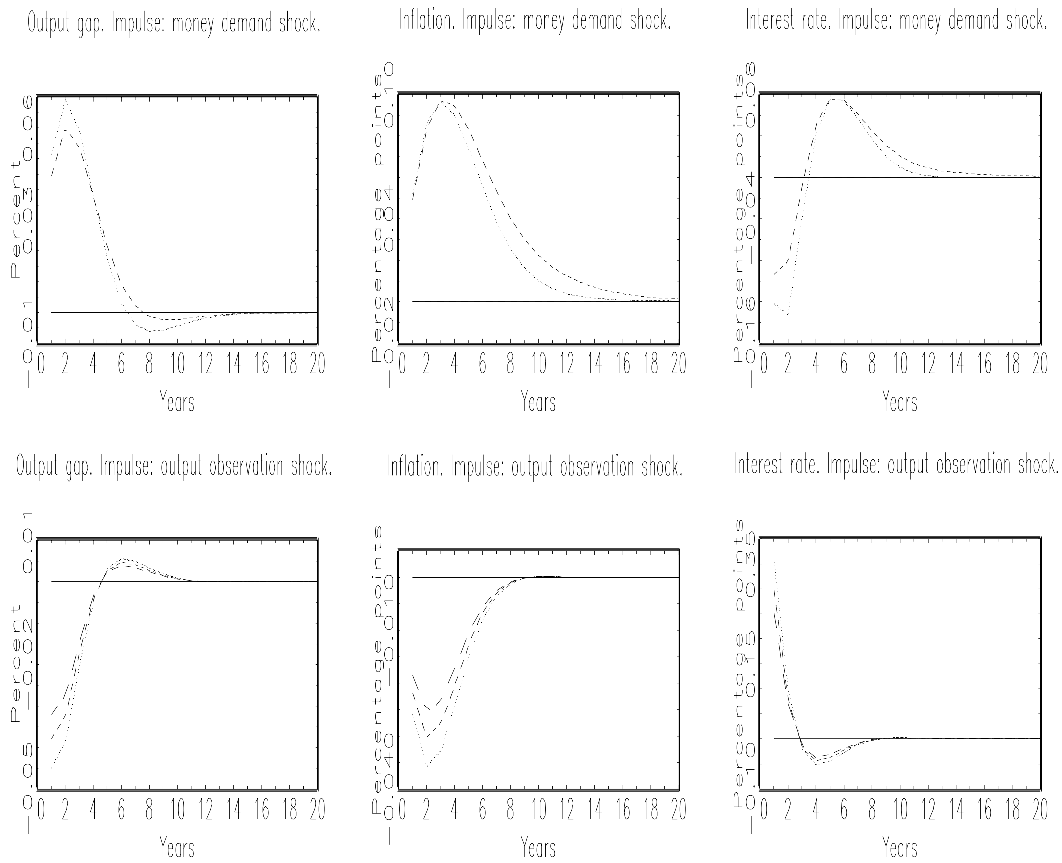


Figure 1 continued.

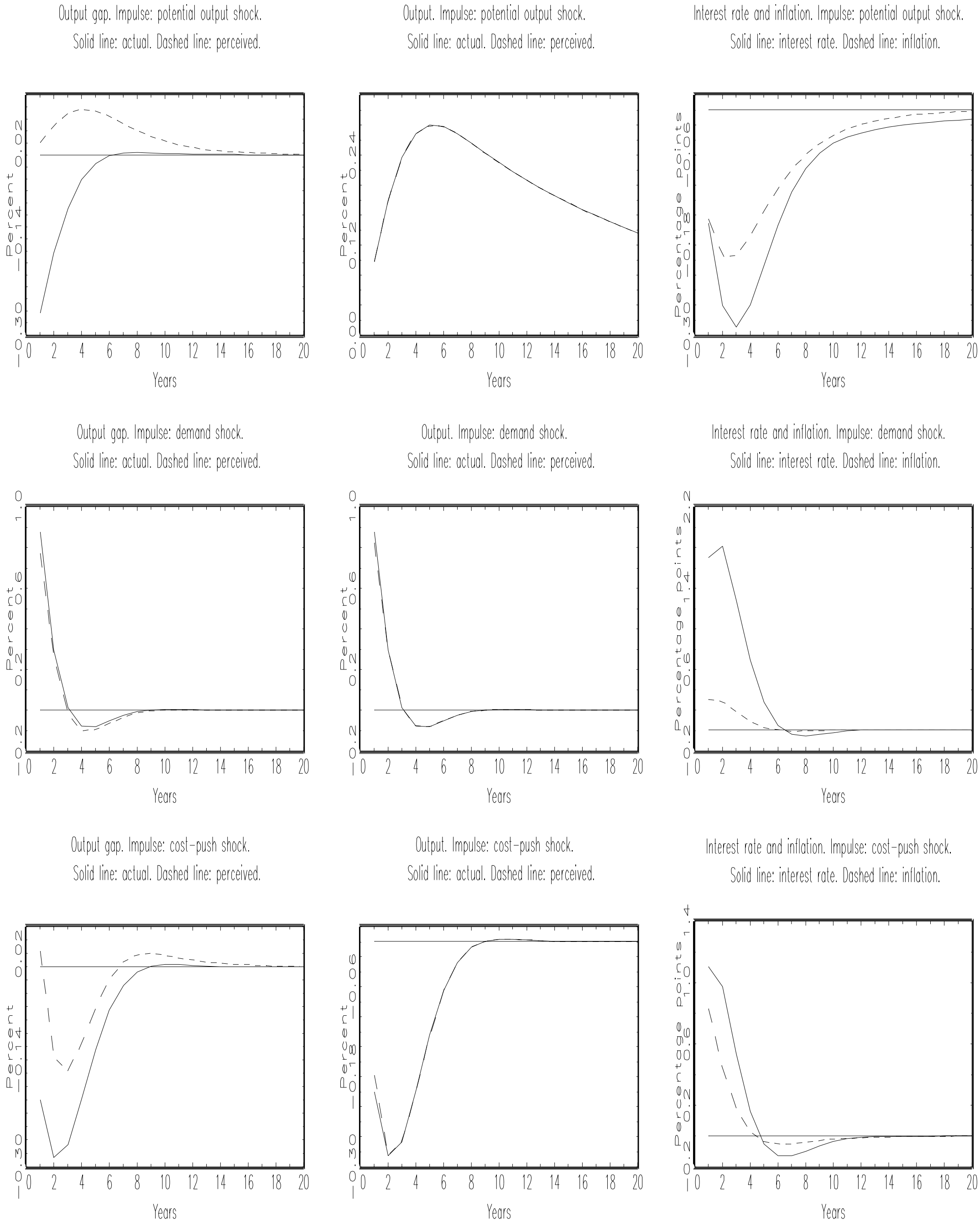


Figure 2: Actual and perceived impulse responses. Case of incomplete information with money, std(MD)=0.25.

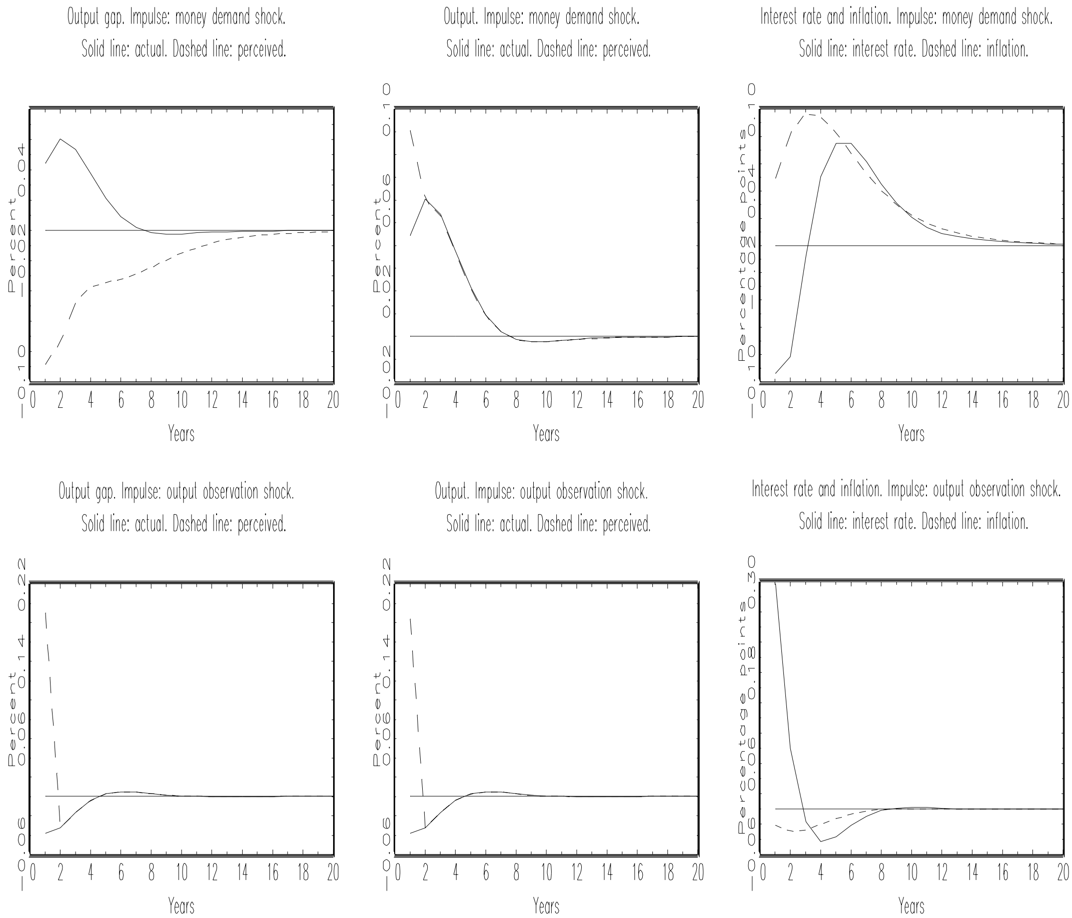


Figure 2 continued.

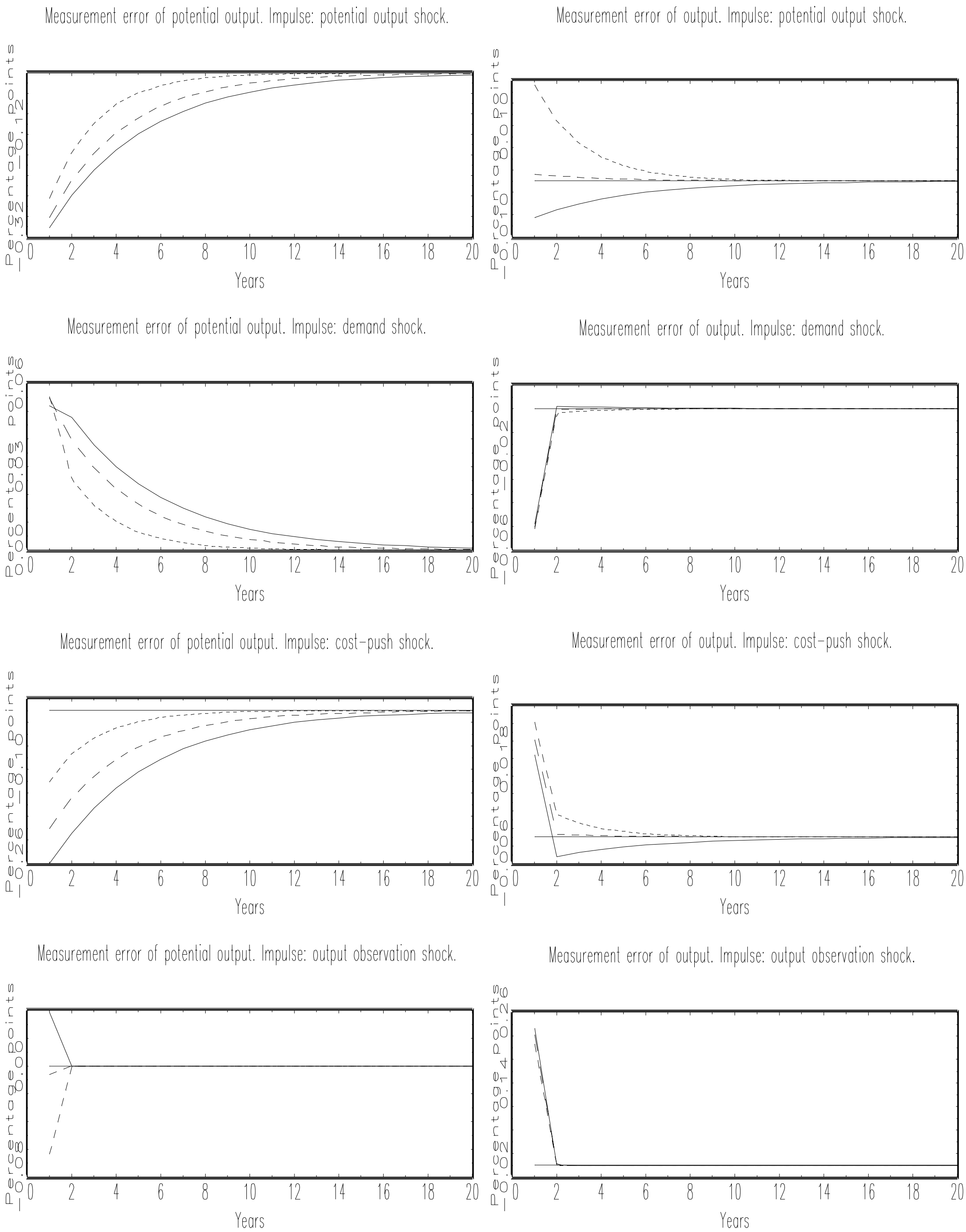


Figure 3: Perception errors.
Solid line: without money. Dashed line: with money, std(MD)=0.25. Short dashes: with money, std(MD)=0.12.

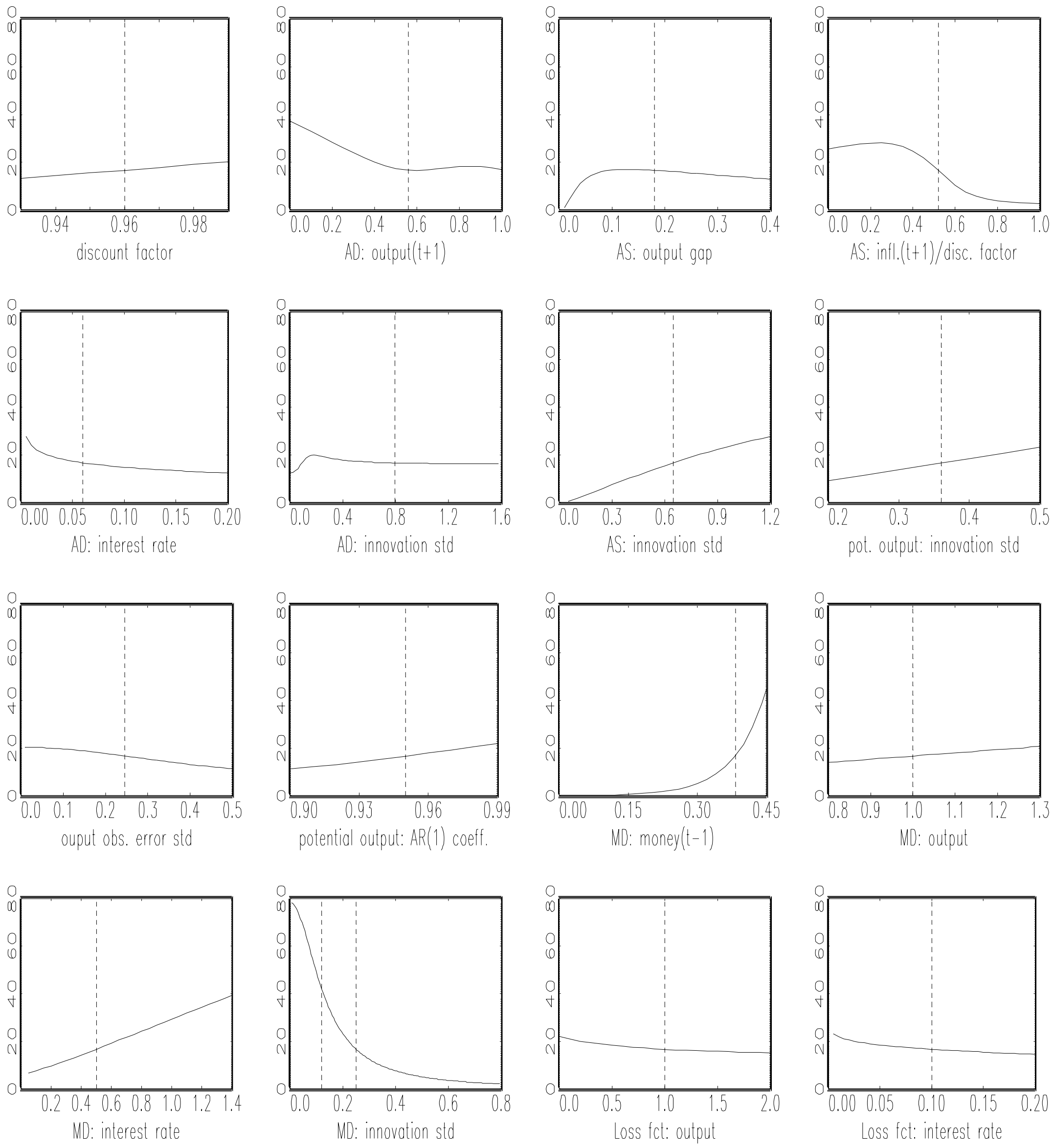


Figure 4: Non-baseline parameter values. The gain from observing money: the percentage reduction in the loss caused by incomplete information.

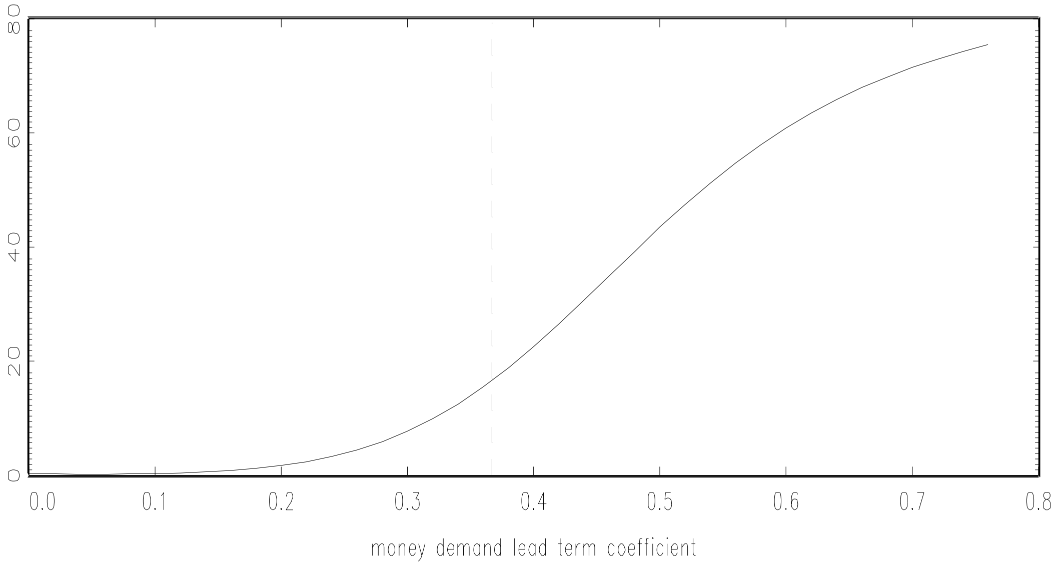


Figure 5: Non-baseline money demand. The gain from observing money: the percentage reduction in the loss caused by incomplete information.

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