BANCA D'ITALIA
EUROSISTEMA

Temi di Discussione

(Working Papers)

Imperfect information, real-time data and monetary policy in the euro area

by Stefano Neri and Tiziano Ropele

March 2011

Number 802

BANCA D'ITALIA
EUROSISTEMA

Temi di discussione

(Working papers)

Imperfect information, real-time data and monetary policy in the euro area

by Stefano Neri and Tiziano Ropele

Number 802 - March 2011

IMPERFECT INFORMATION, REAL-TIME DATA AND MONETARY POLICY IN THE EURO AREA

by Stefano Neri* and Tiziano Ropele*

Abstract

An important concern for the European Central Bank (ECB), and all central banks alike, is the necessity of making decisions in real time under conditions of great uncertainty about the underlying state of the economy. We address this concern by estimating on real-time data a New Keynesian model for the euro area under the assumption of imperfect information. In comparison to models that maintain the assumption of perfect information and are estimated on ex-post revised, we find that: (i) the estimated policy rule becomes more inertial and less aggressive towards inflation; (ii) the ECB is confronted with a more severe trade-off in the stabilization of inflation and the output gap.

JEL Classification: E47, E52, E58.
Keywords: monetary policy, imperfect information, real-time data.

Contents

* Bank of Italy, Economic Outlook and Monetary Policy Department.

1 Introduction[1]

[...] The measurement issues I just raised point to another important concern of policymakers, namely, the necessity of making decisions in "real time" under conditions of great uncertainty – including uncertainty about the underlying state of the economy – and without the benefit of hindsight. Speech by Chairman Ben S. Bernanke at the Federal Reserve Bank of Boston 53^{rd} Annual Economic Conference, Chatham, MA 9 June 9 2008.

Most of New Keynesian dynamic stochastic general equilibrium (DSGE) models currently in use for studying monetary policy assume that agents, including the central bank, know perfectly the state of the economy and are frequently estimated using ex-post revised data (e.g. Smets and Wouters, 2003). However, as stressed in the above quotation, such theoretical setting and empirical validation strategy stand at odds with monetary policymaking in reality, conducted instead under pervasive uncertainty. In this paper, we abandon these two common practices and analyse the implications of *real-time data* and *imperfect information* for monetary policy through the lens of an estimated New Keynesian DSGE model.

The implications, and potential perils, of using ex-post revised versus real-time data for the evaluation of macroeconomic policy have been documented by many authors (see Croushore, forthcoming, and the references therein). In a series of breakthrough articles, Athanasios Orphanides has drawn attention to the limitations from assessing the performance of historical monetary policy rules based on ex-post revised data. Orphanides (2001) estimates a simple monetary policy rule using U.S. real-time data for the output gap and inflation and finds that real-time policy recommendations differ considerably from those based on ex-post revised data. In addition, granted that an active monetary policy can secure economic stability in the absence of informational problems, Orphanides (2003) claims that less aggressive policies might even prove more effective when informational limitations are explicitly considered. Indeed, in this latter case a more muted degree of activism would at the same time lessen the unintended response of monetary policy to

[1] The authors would like to thank Paolo Del Giovane, Eugenio Gaiotti, Dale Henderson, Pelin Ilbas, Giulio Nicoletti, Lucrezia Reichlin, Lars Svensson, John Williams and all the participants at the Norges Bank Workshop on "Optimal Monetary Policy", 21-22 November 2008, the 10^{th} EABCN Workshop on "Uncertainty over the Business Cycle", 30-31 March 2009 held at the European Central Bank, and the 16th International Conference of the Society for Computational Economics held in London on 15-17 July 2010 for all the comments and suggestions. Correspondence: Banca d'Italia, Economic Outlook and Monetary Policy Department. Via Nazionale, 91, 00184, Rome, Italy. E-mail: stefano.neri@bancaditalia.it. The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Eurosystem or the Banca d'Italia.

the noise embedded in real-time data.[2]

The uncertainty surrounding the real-time assessment of the current (and possibly past) state of the economy may arise because of data measurement errors and publication lags. The first releases of many macroeconomic series are provisional and subject to subsequent revisions. Data revisions, which may occur after months, quarters or even years, are needed for different reasons: to incorporate more complete or better sources; to incorporate updated seasonal factors; to reflect improved statistical methods or changes in concepts, definitions, and classifications; or just to correct computational errors. Giannone et al. (2010) examine the properties of data revisions for a large set of euro area macroeconomic variables (constructed in the real-time version by the Euro Area Business Cycle Network, EABCN). In particular, their results show that real variables (e.g., GDP, industrial production and the unemployment rate) are more often and more sizeably revised than nominal variables (price indices and monetary aggregates).[3]

With regards to publication lags, initial releases of many macroeconomic statistics usually lag the period they refer to. For example, Eurostat, the statistical office of the European Union, makes a first release of the euro-area GDP available at the beginning of the third month following the end of the reference quarter; for the monthly Harmonised Index of Consumer Prices (henceforth HICP) the first release occurs around the middle of the first month following the reference period.[4]

The incomplete knowledge of the state of the economy is also due to the fact that some economic concepts relevant for policy-making are simply not measurable using conventional data-collection techniques. Prominent examples of these types of economic notions are the so-called natural rates: potential output (i.e. the flexible price level of output) allows to compute the output gap and to determine whether the economy is operating at an inflationary or deflationary conjuncture; the natural rate of interest (i.e. the level of real interest rates consistent with an output gap of zero) provides instead a benchmark against which to evaluate the monetary policy stance. Typically these economic concepts are estimated from other macroeconomic data or inferred from economic surveys. Recent econometric studies have proposed statistical methods and structural macroeconometric techniques to estimate natural rates (Laubach and Williams, 2003). Ehrmann and Smets (2003) argue that output-gap mismeasurement may pose a serious problem for the

[2] Other authors have estimated monetary policy rules with real-time data. E.g, Clausen and Meier (2005) for Germany and Gerdesmeier and Roffia (2005) for the euro area. Kozicki (2004) provides an overview of the real-time literature and discusses how data revisions may affect the evaluation and design of monetary policy.

[3] In an earlier study, Coenen et al. (2005) found similar results.

[4] To somewhat ease the issue related to the timeliness of macroeconomic data the Eurostat also produces "flash" estimates for both real GDP and HICP, which are usually published at the end of each reference period.

correct assessment of the state of the economy and for the conduct of monetary policy. Orphanides and Williams (2002) suggest that underestimating the unreliability of real-time estimates of the unobservable natural rates may lead to policies that are very costly in terms of the stabilization of the economy.

To analyze the monetary policy implications of real-time data and imperfect information we solve and estimate on euro area data three versions of a small-scale New Keynesian model. The sample period starts in 1999Q1, at the time European Central Bank (ECB) took the responsibility for the single monetary policy, and ends in 2008Q3. The first model, labeled $\mathcal{PI}$-$\mathcal{EP}$, features perfect information and is estimated with ex-post revised data. As said above, this is *de facto* the common practice for solving and validating New Keynesian DSGE models (see Christiano et al., 2005, for the U.S. and Smets and Wouters, 2003, for the euro area). The second model, labeled $\mathcal{PI}$-$\mathcal{RT}$, features perfect information, as the $\mathcal{PI}$-$\mathcal{EP}$ model, but is estimated with real-time data. Recent studies such as Edge et al. (2009) and Kolasa et al. (2009) have compared the forecasting properties of DSGE models with those of VAR models and surveys in a real-time environment. The third model, labeled $\mathcal{II}$-$\mathcal{RT}$, incorporates the assumption of imperfect information à la Svensson and Woodford (2003) and is estimated with real-time data.

It is worthwhile here to clarify two aspects of our analysis. First, all three models are solved under the hypothesis of rational expectations. Under perfect information, i.e. the $\mathcal{PI}$-$\mathcal{EP}$ and $\mathcal{PI}$-$\mathcal{RT}$ models, agents observe all the state variables including shocks and the decision rules are obtained by standard (Uhlig, 1999). Therefore, in terms of the solution of the models, the $\mathcal{PI}$-$\mathcal{EP}$ and $\mathcal{PI}$-$\mathcal{RT}$ cases give rise to the same policy functions. Under imperfect information, i.e. the $\mathcal{II}$-$\mathcal{RT}$ model, agents are incompletely informed about the state of the economy and they base their decisions upon an estimate of the unobservable state variables. Thus, in this case agents solve two problems: an optimal decision problem and an optimal filtering problem. Second, with regards to the empirical analysis, we assume that the econometrician estimates each model using a set of variables which are observed with measurement error. In particular, depending on the model, the econometrician, uses ex-post revised or real-time data. Therefore, the models $\mathcal{PI}$-$\mathcal{EP}$ and $\mathcal{PI}$-$\mathcal{RT}$ are equal in terms of solution but differ as for the data used in the estimation.

Our findings can be summarized as follows. First, the empirical performance of the $\mathcal{PI}$-$\mathcal{EP}$ and $\mathcal{II}$-$\mathcal{RT}$ models is broadly similar. Second, moving from $\mathcal{PI}$-$\mathcal{EP}$ to the more realistic environment $\mathcal{II}$-$\mathcal{RT}$ the posterior median of the coefficient on inflation in the monetary policy rule decreases while those on lagged interest rate and the output gap increase. These results, which are consistent with the findings in Orphanides (2001), suggest that in response to uncertainty stemming from the real-time data and imperfect information, the policy of the ECB becomes more inertial. Third, moving from the $\mathcal{PI}$-

$\mathcal{EP}$ to $\mathcal{II}$-$\mathcal{RT}$ model, the efficient frontier (i.e. the lowest achievable combinations of unconditional inflation and output gap volatilities), deteriorates suggesting a worsening of the trade-off faced by the ECB.

Other authors have estimated New Keynesian DSGE models under imperfect information. One recent example is Collard et al. (2009). In their article, the authors undertake a comprehensive study of the role of alternative informational settings for macroeconomic fluctuations. Beside the standard case of perfect information they look at three variants of imperfect information, one of which is the incomplete knowledge of state of the economy.[5] The models are estimated on U.S. ex-post revised quarterly data using Bayesian methods and are compared in terms of various criteria (e.g. empirical fit, unconditional second moments, impulse response functions). The main finding is that the model with the imperfect knowledge of the state of the economy has considerable explanatory power for the U.S. business cycle. Collard et al. (2009) also show that the assumption of imperfect information represents an important source of endogenous persistence *per se*, which allows to rely less on *ad hoc* devices, such as price indexation or habit formation. Levine et al. (2010) estimate a model akin to Collard et al. (2009) on U.S. ex-post revised data using Bayesian methods and report similar results.[6] Lippi and Neri (2007) analyze the role of monetary indicators using a small-scale DSGE model with imperfect information and optimal discretionary policy. They estimate the model by maximum-likelihood using euro area ex-post revised data. Boivin and Giannoni (2008) propose an empirical framework for the estimation of a medium-scale New Keynesian DSGE model that exploits the information from a data-rich environment under asymmetric imperfect information. In particular, in their theoretical setting only the central bank (and the econometrician) is imperfectly informed about the state of the economy. While the structural parameters of the model are calibrated, the authors estimate the unobserved state of the economy using U.S. ex-post revised data and then evaluate the welfare implication of different policies and different information sets. Their results show that responding naively to observable but noisy indicators, the central bank may perform very poorly in terms of welfare. Filtering out the noise in observable variables is thus key to conduct policy and may substantially increase the welfare gains. Exploiting the information available in large macroeconomic data sets may be very valuable for the central bank to get a more accurate and precise assessment of the state of the economy (Boivin and Giannoni, 2006).

Our study extends and complements the aforementioned analyses in two aspects. First, we estimate the models with either ex-post revised or real-time data. Second, we study how the informational set up and the use of real-time data affects the trade-off faced by

[5] The other two versions of imperfect information rely on the misperception between temporary and permanent shocks and the unobservability of the inflation target of the central bank.

[6] Bomfim (2001) finds similar results in the context of real business cycle models.

monetary policy.

The remainder of the paper is organized as follows. Section 2 presents the model, describes monetary policy and illustrates the signal extraction problem. Section 3 describes the data and the estimation. Section 4 discusses the results and Section 5 concludes.

2 A small-scale new Keynesian model

In order to analyze the monetary policy implications of imperfect information and real-time data we use a small-scale New Keynesian DSGE model similar to the one in Ehrmann and Smets (2003) and Benati (2008). Though much of the theoretical appealing of New Keynesian models relies upon the fact that aggregate economic relationships are micro-founded and depend on structural parameters, for the scope of our analysis we directly estimate the parameters in reduced-form as in Lippi and Neri (2007).

Table 1 presents the model. For any variable z the writing $z_{t+k|t}$ denotes the expected value of z at time $t+k$ conditioned on information available at time t.

Table 1. A small-scale New Keynesian DSGE model

Laws of motion of output and inflation:

$$y_t = \delta y_{t-1} + (1-\delta)\, y_{t+1|t} - \theta\left(r_t - \pi_{t+1|t}\right) + u_{d,t} \tag{M.1}$$

$$\pi_t = \alpha\pi_{t-1} + (1-\alpha)\,\pi_{t+1|t} + \kappa\left(y_t - \overline{y}_t\right) + u_{c,t} \tag{M.2}$$

Exogenous processes:

$$\overline{y}_t = \rho_{\overline{y}}\overline{y}_{t-1} + \varepsilon_{\overline{y},t}, \text{ with } \varepsilon_{\overline{y},t} \sim N\left(0, \sigma^2_{\overline{y}}\right) \tag{M.3}$$

$$u_{d,t} = \rho_d u_{d,t-1} + \varepsilon_{d,t}, \text{ with } \varepsilon_{d,t} \sim N\left(0, \sigma^2_d\right) \tag{M.4}$$

$$u_{c,t} = \rho_c u_{c,t-1} + \varepsilon_{c,t}, \text{ with } \varepsilon_{c,t} \sim N\left(0, \sigma^2_c\right) \tag{M.5}$$

Monetary policy:

$$r_t = \phi_r r_{t-1} + (1-\phi_r)\left[\phi_\pi \pi^{year}_{t+1|t} + \phi_x\left(y_{t|t} - \overline{y}_{t|t}\right)\right] \tag{M.6}$$

$y_t =$ output; $\pi_t =$ inflation; $\pi^{year}_t =$ year-on-year inflation $\equiv \pi_t + \pi_{t-1} + \pi_{t-2} + \pi_{t-3}$; $r_t =$ nominal interest rate; $\overline{y}_t =$ potential output; $u_{d,t} =$ demand shock; $u_{c,t} =$ supply shock; $\varepsilon_{\overline{y},t} =$ innovation to $\overline{y}_t$; $\varepsilon_{d,t} =$ innovation to $u_{d,t}$; $\varepsilon_{c,t} =$ innovation to $u_{c,t}$.

Equation (M.1) represents the hybrid IS curve and describes the aggregate demand side of the economy. Current output y_t depends positively on its one-period lagged and future expected values and negatively on the ex-ante real interest rate. Aggregate demand is subject to the shock $u_{d,t}$. Depending on the value of δ, which can be justified on the basis of habit formation in consumption, output dynamics may display a varying degree of backward- and forward-lookingness. The coefficient θ is the intertemporal elasticity of substitution and measures the sensitivity of output to changes in the ex-ante real interest rate. Equation (M.2) represents the hybrid New Keynesian Phillips curve (NKPC) and describes the aggregate supply side of the economy. Current inflation π_t relates positively to its one-period lagged and future expected values and to the output gap, i.e. the difference between actual output y_t and potential output $\overline{y}_t$. Note that potential output is treated as an exogenous stochastic process. The aggregate supply schedule is also subject to a stochastic shock $u_{c,t}$. The parameter α can be motivated by assuming rule-of-thumb behaviour (as in Galí and Gertler, 1999) or price indexation to past inflation (as in Christiano et al., 2005) in the Calvo model. As reported in equations (M.3), (M.4) and (M.5), the three exogenous variables follow stationary AR(1) processes, whose innovations are pair wise orthogonal, serially uncorrelated and normally distributed. Finally, equation (M.6) describes the central bank's behaviour. It simply posits that the monetary authority gradually adjusts the nominal interest rate (r_t) in response to one-quarter-ahead expected annual inflation ($\pi^{year}_{t+1|t}$) and to current estimate of output gap ($y_{t|t} - \overline{y}_{t|t}$).[7]

Throughout our analysis, we assume there is *no model uncertainty*.[8] This means that agents are aware of how the economy functions and know that equations (M.1)-(M.5) represent the true laws of motion that govern the dynamics of output and inflation.

2.1 Imperfect information and the signal-extraction problem

In this section we formalize the assumption of imperfect information following Svensson and Woodford (2003).

First of all, we let vectors X_t and x_t include respectively the state (or predetermined) and the jump (or non-predetermined) variables, whereas vector ε_t the innovations to the exogenous processes. By vectors $X_{t|t}$ and $x_{t|t}$ we denote the best estimates (which we specify below) of X_t and x_t, given the information set available at time t. Note that the nominal interest rate rule (M.6) can be written as

$$r_t = \mathbf{F}_1 X_{t|t} + \mathbf{F}_2 x_{t|t}, \tag{1}$$

[7] We have chosen an interest rate rule that reacts to one-quarter-ahead expected annual inflation for two reasons. First, it has been shown empirically that aggregate economic activity and inflation respond with long lags to monetary policy; this evidence then calls for a preemptive monetary policy behaviour. Second, Smets (2003) has recently shown for the euro area that the optimal policy horizon to achieve price stability becomes shorter the larger the degree of forward-lookingness and the slope of the NKPC.

[8] Kilponen (2004) studies robust control under model uncertainty and imperfect information.

where vectors $\mathbf{F}_i$, with $i = 1, 2$, contain the policy coefficients. So, substituting (1) in (M.1), it is possible to cast equations (M.1)-(M.5) in the format,

$$\begin{bmatrix} X_{t+1} \\ x_{t+1|t} \end{bmatrix} = \begin{bmatrix} \mathbf{A}_{11}^1 & \mathbf{A}_{12}^1 \\ \mathbf{A}_{21}^1 & \mathbf{A}_{22}^1 \end{bmatrix} \begin{bmatrix} X_t \\ x_t \end{bmatrix} + \begin{bmatrix} \mathbf{A}_{11}^2 & \mathbf{A}_{12}^2 \\ \mathbf{A}_{21}^2 & \mathbf{A}_{22}^2 \end{bmatrix} \begin{bmatrix} X_{t|t} \\ x_{t|t} \end{bmatrix} + \mathbf{B} \begin{bmatrix} \varepsilon_{t+1} \\ 0 \end{bmatrix}, \tag{2}$$

where $\mathbf{A}_{ij}^1$, $\mathbf{A}_{ij}^2$ and $\mathbf{B}$, with $i = 1, 2$ and $j = 1, 2$, represent matrices of appropriate dimension containing the model parameters. It is worthwhile to note that the above model representation is convenient as it allows to consider the case of perfect information by simply imposing that $X_t = X_{t|t}$ and $x_t = x_{t|t}$.

At time t, the information set available to agents is represented by a vector Z_t of observable variables, which are noisy indicators of X_t and x_t according to mapping:

$$Z_t = \begin{bmatrix} \mathbf{D}_1^1 & \mathbf{D}_2^1 \end{bmatrix} \begin{bmatrix} X_t \\ x_t \end{bmatrix} + v_t \tag{3}$$

where $\mathbf{D}_1^i$, with $i = 1, 2$, are matrices of appropriate dimension and v_t is the vector of measurement errors. Throughout, we assume that v_t is independently and identically normally distributed and uncorrelated with u_{t+1}, at all leads and lags.

Under imperfect information agents estimate the state of the economy (X_t) observing a set of indicator variables (Z_t) and consistently with the model's fundamental dynamics given by (M.1)-(M.5). As originally emphasized by Pearlman et al. (1986), the assumption of imperfect information poses rather complex problems in terms of the signal-extraction problem agents need to solve, as the model dynamics is also driven by non-predetermined variables. Svensson and Woodford (2003) show that the estimate of non-predetermined variables relates linearly to the estimate of the state vector according to:

$$x_{t|t} = \mathbf{G}^* X_{t|t} \tag{4}$$

where $\mathbf{G}^*$ is the solution to the non-linear matrix equation defined as

$$\mathbf{G} = (\mathbf{G}\mathbf{A}_{12} - \mathbf{A}_{22})^{-1} (\mathbf{A}_{21} - \mathbf{G}\mathbf{A}_{11}),$$

provided that $(\mathbf{G}\mathbf{A}_{12} - \mathbf{A}_{22})$ is invertible.[9] Furthermore, Svensson and Woodford (2003) show that the problem of finding the solution to $\mathbf{G}^*$ is independent from the computation of $X_{t|t}$ (i.e., the so-called *separation principle*).

Exploiting the result (4), it is possible to cast the model in terms of only predetermined variables. Such a representation is convenient because it allows to use the Kalman filter to

[9] As in Svensson and Woodford (2003), $\mathbf{A}_{ij} = \mathbf{A}_{ij}^1 + \mathbf{A}_{ij}^2$, where $i = 1, 2$ and $j = 1, 2$.

estimate the state of the economy based on the observable variables. After some algebra, the model dynamics can be expressed as:

$$X_{t+1} = \mathbf{H}X_t + \mathbf{J}X_{t|t} + \mathbf{B}\varepsilon_{t+1} \tag{5}$$

$$X_{t|t} = X_{t|t-1} + \mathbf{K}\left(Z_t - Z_{t|t-1}\right) \tag{6}$$

$$Z_t = \mathbf{L}X_t + \mathbf{M}X_{t|t} + v_t \tag{7}$$

where

$$\mathbf{H} = \mathbf{A}_{11}^1 - \mathbf{A}_{12}^1\left(\mathbf{A}_{22}^1\right)^{-1}\mathbf{A}_{21}^1, \tag{8}$$

$$\mathbf{J} = \mathbf{A}_{12}^1\left[\left(\mathbf{A}_{22}^1\right)^{-1}\mathbf{A}_{21}^1 + \mathbf{G}^*\right] + \mathbf{A}_{11}^2 + \mathbf{A}_{12}^2\mathbf{G}^*, \tag{9}$$

$$\mathbf{L} = \mathbf{D}_1^1 - \mathbf{D}_2^1\left(\mathbf{A}_{22}^1\right)^{-1}\mathbf{A}_{21}^1, \tag{10}$$

$$\mathbf{M} = \mathbf{D}_2^1\left[\left(\mathbf{A}_{22}^1\right)^{-1}\mathbf{A}_{21}^1 + \mathbf{G}^*\right], \tag{11}$$

$$\mathbf{K} = \mathbf{PL}'\left(\mathbf{LPL}' + \Sigma_v^2\right)^{-1}. \tag{12}$$

Equation (5) gives the law of motion of the state variables. Equation (6) describes the updating rule of the current state estimate based on the most recent available information contained in the indicator variables. The matrix **K** represents the Kalman gain and weighs the informative content of each indicator. The estimate of the state of the economy depends both on the covariance matrix of the structural innovations Σ_u^2 and of the measurement error Σ_v^2. Finally, equation (7) links the indicator variables to the current state of the economy, its estimate and the measurement errors. Under perfect information ($X_{t|t} = X_t$), the solution of the model becomes:

$$X_{t+1} = \left[\tilde{\mathbf{H}} + \tilde{\mathbf{J}}\right]X_t + \tilde{\mathbf{B}}\varepsilon_{t+1} \tag{13}$$

$$Z_t = \left[\tilde{\mathbf{L}} + \tilde{\mathbf{M}}\right]X_t + v_t \tag{14}$$

where the matrices with ˜ are obtained through standard methods (e.g. Uhlig, 1999).

Comparison of the solution of the models with imperfect and perfect information suggests that in the former case, the signal-extraction problem can, in principle, act as an inertial mechanism. This result has been recently emphasized by Collard and Dellas (2010), who show that the assumption of imperfect information introduces *per se* a source of endogenous persistence that enhances the empirical fit of estimated small-scale New Keynesian models. Since the estimate of the current state of the economy is a distributed lag of observable variables, agents only gradually refine their estimate of the state of the economy and thus respond cautiously to what they perceive as structural shocks (Aoki, 2003). More recently, Collard et al. (2009) have shown that the endogenous persistence generated by signal extraction does indeed help improving the empirical fit of a small-scale New Keynesian model. Second, combining equations (1), (4) and (6) yields:

$$r_t = \left(\mathbf{F}_1 + \mathbf{F}_2\mathbf{G}^*\right) X_{t|t-1} + \left(\mathbf{F}_1 + \mathbf{F}_2\mathbf{G}^*\right) \mathbf{K} \left(Z_t - Z_{t|t-1}\right) \quad . \tag{15}$$

which shows how imperfect information affects the policy rate. As in Orphanides (2003) the presence of noise in the variables that enter the policy rule introduces undesirable movements in the interest rate that generates unnecessary fluctuations in the economy.

3 Empirical analysis

In this section we first illustrate the main steps involved in the Bayesian estimation under imperfect information. Next we describe the macroeconomic data and the prior distribution of parameters.

3.1 Bayesian estimation under imperfect information

The Bayesian approach combines the prior distributions for the parameters with the likelihood function to form the posterior density of the parameters:

$$P\left(\Theta|d\right) \propto P\left(d|\Theta\right) P\left(\Theta\right)$$

where Θ is the vector of parameters, $P\left(\Theta\right)$ is the prior and $P\left(d|\Theta\right)$ the likelihood of the data d. Since the posterior distribution does not belong to any known family, inference is based on the Metropolis algorithm, which is commonly used in Bayesian estimation of DSGE (e.g. Smets and Wouters, 2003).

To compute the likelihood function we construct an augmented state-space representation defined by the transition equation

$$Q_{t+1} = \widetilde{\mathbf{A}} Q_t + \widetilde{\mathbf{B}} \epsilon_{t+1}, \tag{16}$$

and measurement equation

$$d_t = \widetilde{\mathbf{L}} Q_t + \widetilde{\mathbf{M}} v_t, \tag{17}$$

where $Q_t = \left[\begin{array}{cc} X_t & X_{t|t-1} \end{array}\right]'$, $d_t = \left[\begin{array}{cc} Z_t & r_t \end{array}\right]'$, $\epsilon_{t+1} = \left[\begin{array}{cc} \varepsilon_{t+1} & v_t \end{array}\right]'$ and $\widetilde{\mathbf{A}}$, $\widetilde{\mathbf{B}}$, $\widetilde{\mathbf{L}}$ and $\widetilde{\mathbf{M}}$ are matrices of appropriate dimension. Given the representation (16)-(17), the application of the Kalman filter provides a convenient method to compute the likelihood function of the observable vector d_t. However, it is worthwhile noting that the assumption of imperfect information complicates somewhat this computation as the vector v_t appears both in (16) and (17). The correlation between ϵ_{t+1} and v_t modifies the Kalman gain matrix K_t by the addition of matrix V_3:[10]

$$K_t \equiv \left(\widetilde{\mathbf{A}}\Sigma^2_{t|t-1}\widetilde{\mathbf{L}}' + \widetilde{\mathbf{B}}V_3\right)\left(\widetilde{\mathbf{L}}\Sigma^2_{t|t-1}\widetilde{\mathbf{L}}' + V_2\right)^{-1} \tag{18}$$

where $\Sigma^2_{t|t-1}$ is the covariance matrix of the forecast errors of Q_t. If the measurement errors in the model are different from those included by the econometrician in (17), then the matrix V_3 is the null one. This is also true when agents have perfect information on the states of the model. In both cases the Kalman gain becomes:

$$K_t \equiv \widetilde{\mathbf{A}}\Sigma^2_{t|t-1}\widetilde{\mathbf{L}}'\left(\widetilde{\mathbf{L}}\Sigma^2_{t|t-1}\widetilde{\mathbf{L}}' + V_2\right)^{-1} \tag{19}$$

since $X_t = X_{t|t-1}$ and Q_t is X_t. We decided to estimate jointly the standard deviation of the measurement errors and the parameters since Lippi and Neri (2007) found that joint estimation of the two sets of parameters performs better than the two-stage method, adopted in Ehrmann and Smets (2003), in terms of empirical performance.

3.2 Data

We use quarterly data for the euro area from 1999:Q1 through 2008:Q3 (see figures 1a and 1b). The sample period starts at the beginning of the European Monetary Union, when the ECB took over the responsibility for the single monetary policy, and ends before the bankruptcy of Lehman Brothers. We group the data into core and non-core observable variables, the former having a direct counterpart in the theoretical model. Table 2 describe the time series included in the real-time and in the ex-post revised data sets.

3.2.1 Core observable variables

Data on the nominal interest rate refer to the minimum bid rate (henceforth, MBR) on the main refinancing operations of the ECB.[11] We use the MBR rather than a money market rate (for example the 3-month Euribor rate) in order to rule out possible estimation biases due to the money market turmoil that started in the summer of 2007.[12] Inflation is measured by the year-on-year changes in the HICP. The ex-post revised series of real GDP is taken from the Eurostat while the same series in real-time is taken from the

[10] The presence of V_3 also modifies the update of the covariance matrix of the forecast errors of the state variables $\Sigma^2_{t+1|t}$. See Lippi and Neri (2005) for a detailed derivation of the matrix V_3. The matrix V_2 is given by $M\Sigma^2_v M' + \sigma_r$ where σ_r is the measurement error attached to the policy rate.

[11] Until June 2000 the ECB conducted the main refinancing operations at fixed rate. From July 2000 to October 2008 they were conducted at variable rate.

[12] From August 2007 to December 2007 the spread between the 3-month Euribor rate and the MBR averaged at 65 basis points and increased up to 180 b.p. after the bankruptcy of Lehman Brothers.

Euro Area Business Cycle Network (EABCN). The series for the output gap (henceforth, GAP), in ex-post revised as well as real-time terms, are constructed by averaging the estimates produced by the Organisation for Economic Co-operation and Development (OECD) and the International Monetary Fund (IMF). As in Orphanides (2001), real-time data are compiled by considering the first available release. Figure 1a show that revisions to the first release have been sizable, in particular in the early years of the European Monetary Union.[13] One possible explanation is that in the early years of the monetary union structural changes in the economies, also caused by the run-up to 1999, may have made more difficult the estimation of potential output for the aggregate of the euro area.

The following set of relations define the core measurement equations:

$$\begin{bmatrix} MBR_t \\ HICP_t \\ GDP_t \\ GAP_t \end{bmatrix} = \begin{bmatrix} r_t \\ \pi_t^{year} \\ y_{t-1} \\ y_{t-1} - \overline{y}_{t-1} \end{bmatrix} + \begin{bmatrix} v_{mbr,t} \\ v_{hicp,t} \\ v_{gdp,t} \\ v_{gap,t} \end{bmatrix} \tag{20}$$

where the $v's$ are the measurement errors. It is worthwhile noting that, as in Lippi and Neri (2007), we assume that the information of GDP and GAP available at time t is related to the unobservable theoretical counterparts with one-quarter, regardless of whether the data are in real time or ex-post revised. This assumption is meant to capture the time lags in the release of real GDP and the output gap. As already said in the Introduction, Eurostat publishes the first relase of the euro-area GDP at the beginning of the third month following the end of the reference quarter.[14]

3.2.2 Non-core observable variables

The assumption that the central bank reacts only to few variables measuring the current cyclical conditions is clearly unrealistic. Similarly to Boivin and Giannoni (2006) we supplement the agents'(and the econometrician's) information set with some extra observable variables, namely an indicator of inflation expectations and two indicators of the conjunctural economic outlook. The indicator of one-quarter-ahead expected annual inflation (henceforth, INFL) is taken from Consensus Economics while the Purchasing Managers' Index (henceforth, PMI) for the manufacturing sector and the €-coin are taken, respec-

[13] Koske and Pain (2008) also found substantial revisions of real-time annual estimates of the output gap for 21 OECD member countries.

[14] No major difference in terms of the results of the paper is found when we relate output and the output gap at time t to their empirical counterparts in the same quarter.

tively from Markit Economics and CEPR/Banca d'Italia.[15]

In particular, we assume that:

$$\begin{bmatrix} INFL_t \\ PMI_t \\ ECOIN_t \end{bmatrix} = \begin{bmatrix} \pi^{year}_{t+1|t} \\ y_t - y_{t-1} \\ y_t - y_{t-1} \end{bmatrix} + \begin{bmatrix} v_{infl,t} \\ v_{pmi,t} \\ v_{ecoin,t} \end{bmatrix} \tag{21}$$

where the $v's$ are the measurement errors. The advantage of using the indicator variables is that they summarize more information than the actual available series and therefore could help at better estimating the parameters of the model.[16]

Data are transformed as follows: the HICP, the inflation expectations, the MBR, the output gap and €-coin are all de-meaned. Real GDP is linearly detrended assuming a steady-state quarterly growth rate equal to the sample mean (0.45 per cent). The PMI index is log transformed and de-meaned. Figures 1a and 1b display the raw data.

3.3 Prior distribution of parameters

Table 3 reports the summary statistics for the prior distribution of parameters. The mean of the prior distribution for the weight on lagged inflation (α) in the hybrid NKPC and lagged output (δ) in the aggregate demand curve are set to 0.5, the values used in Orphanides (2003) and Orphanides and Williams (2007). Note these figures are close to the estimates reported in Ehrmann and Smets (2003). The means of the prior distribution for the intertemporal elasticity of substitution (θ) and the slope of the hybrid NKPC (κ) are set to 0.25 and 0.1, respectively. These values are close to the estimate in Orphanides (2003). Benati (2008) sets a prior mean for κ of 0.05 and for θ of 0.5. Compared to our prior means, his posterior distributions (see Table XII in the paper) suggest a much lower value for the elasticity of aggregate demand to the real interest rate and a similar value for the elasticity of inflation to the output gap. The mean of the prior distribution of the inflation coefficient in the Taylor rule is set to 0.5 which, taking into account that the ECB targets annual inflation and that we measure the interest rate in quarterly (not annualized) terms, corresponds to a value of 2.0 in the commonly used specification of the Taylor rule, which is larger than the conventional 1.5. The mean of the prior distribution

[15] The €-coin provides an estimate of the monthly growth of euro area GDP after the removal of measurement errors, seasonal and other short-run fluctuations - and is published each month. For more information on €-coin see `http://eurocoin.cepr.org`. The PMI assesses business conditions in the manufacturing sector and is released one working day after the month to which it refers.

[16] We have estimated the models without the indicators to assess the robustness of our findings. While the fit of the policy rate is worse when the indicators are not included, the results concerning the policy trade-offs are similar to those reported in the text.

of the coefficient on the output gap and the lagged interest rate are both set at 0.5. Finally, the mean of the persistence of the shocks and the standard deviations of both the innovations to the shock processes and the measurement errors are set, respectively, at 0.7 and 0.01.

4 Results

In this Section we analyze the monetary policy implications of imperfect information and real-time data by looking at: (*i*) the posterior distributions of the parameters, (*ii*) the empirical fit of the models and (*iii*) the inflation and output gap stabilization trade-off.

4.1 Posterior distributions of the parameters

Table 4 reports the median and 0.95 confidence sets of the parameters in the three models considered, namely $\mathcal{PI}$-$\mathcal{EP}$, $\mathcal{PI}$-$\mathcal{RT}$ and $\mathcal{II}$-$\mathcal{RT}$. Summary statistics are based on 5 parallel chains each one consisting of 250,000 draws from the Metropolis algorithm. One out of fifty draws were kept in order to reduce the impact of the serial correlation of the draws on the computation of the statistics of the posterior distribution. This led to a total of 10,000 draws. Acceptance rates for all the models were around 30 percent. To assess convergence we computed recursive means and potential reduction scale factors. In most of the cases they were all very close to one suggesting that little improvement in convergence could be expected by increasing the number of draws. Figures 2 and 3 report the prior and posterior distributions of the parameters.

Several results are worth mentioning. For most of the parameters in equations (M.1) and (M.2) the posterior median differs substantially from the prior; although the difference is not a sufficient criterion for assessing identification, this suggests that the data have information for these parameters. Both backward- and forward-looking components are needed to explain output and inflation. The posterior median of δ (0.6 across models) suggests that habit formation is an important real rigidity to match the data. The posterior median of α (around 0.15 across models) suggests that price indexation or rule-of-thumb behaviour play a minor role while the forward-looking component is much more important for inflation dynamics. This finding is in line with the results in Galí and Gertler (1999) and Benati (2008). The posterior median of θ (between 0.25 and 0.3 depending on the model), is similar to the estimate in Rabanal and Rubio-Ramírez (2005). The median values of the posterior distribution of the autoregressive coefficients of the shocks are lower than what is usually found in estimated models.

Important differences emerge for the slope of the inflation equation and the coefficients of the monetary policy rule. Overall, the posterior medians of the slope of the NKPC

(κ) takes on low values, though in line with the estimates of, among others, Fuhrer and Moore (1995) and Ireland (2001). The posterior median in the $\mathcal{PI}$-$\mathcal{EP}$ model is 2.1 and 1.5 times smaller than the corresponding values in, respectively, the $\mathcal{II}$-$\mathcal{RT}$ and the $\mathcal{PI}$-$\mathcal{RT}$ models, while the slope in the $\mathcal{II}$-$\mathcal{RT}$ model is 1.5 times larger than the value in the $\mathcal{PI}$-$\mathcal{RT}$ model. Therefore, the real-time dimension of the data and imperfect information are equally important in explaining the increased sensitivity of inflation to the output gap in the more realistic $\mathcal{II}$-$\mathcal{RT}$ model. The value of κ is crucial for the transmission mechanism of monetary policy and, as shown in section 4.3, for the trade-off faced by the ECB. In particular, as this coefficient increases the central bank can control inflation more efficiently by influencing aggregate demand with the policy rate.

For the scope of our paper it is also revealing to compare the posterior median of the coefficients of the interest rate rule across models. The coefficient that measures the policy response to inflation is larger in the $\mathcal{PI}$-$\mathcal{EP}$ model (0.47) than in the $\mathcal{II}$-$\mathcal{RT}$ one (0.31). At the same time, the coefficient on the lagged interest rate increases (from 0.35 to 0.45). Intuitively, when confronted with higher uncertainty the central bank adopts a more inertial behaviour. The coefficient on the output gap also increases from 0.17 to 0.23. By looking at the posterior median values in the $\mathcal{PI}$-$\mathcal{RT}$ model and comparing them with the corresponding statistics in the $\mathcal{PI}$-$\mathcal{EP}$ case one can see that much of the differences in ϕ_x and ϕ_π are explained by the use of real-time data. In contrast, comparison of the median values between the $\mathcal{PI}$-$\mathcal{RT}$ and $\mathcal{II}$-$\mathcal{RT}$ models shows that introducing imperfect information determines a reduction in the coefficient on the output gap (from 0.29 to 0.22). Interestingly, Orphanides (2001) for the U.S. and Gerdesmeier and Roffia (2005) for the euro area find a more muted response to inflation and a larger response to the output gap in a Taylor rule estimated with real-time data. Orphanides (2001) finds a larger degree of interest rate inertia when real-time data for the U.S. are employed.

4.2 Empirical fit of the models

In this section we discuss the empirical performance of the models focusing on the fit of the two variables that are common across our data sets and are usually subject to minor revisions, i.e. the policy rate and inflation. Goodness of fit in a Bayesian framework is a very specific concept that differs from its counterpart in the frequentist analysis. Following Fernańdez-Villaverde and Rubio-Rańirez (2004) we rely on the marginal data density (MDD) as the measure of fit. The MDD summarises the conflicting information contained in the likelihood and in the prior.[17] In computing the MDD of each model we use the modified harmonic mean estimator proposed by Geweke (1999). To overcome the

[17] We thank an anonymous referee for suggesting the comparison based on the conditional marginal data density.

problem that our models have been estimated with partially different data (the output gap and real GDP) we invoke the Bayes theorem and rely on the conditional MDD of the policy rate and inflation. Before discussing the computation of the conditional MDD it is useful to clarify some notation. We denote with D_T^{RT} the set of observable variables in the real time data set excluding the policy rate and inflation and, similarly, D_T^{EP} the corresponding set of variables in the ex-post revised data (see Table 2). We denote with $D_T^C = \{MBR_t, HICP_t\}_{t=0}^T$. It is then possible to show that the conditional MDD of D_T^C for the model with perfect information and ex-post revised data is:

$$p\left(D_T^C | D_T^{EP}, \mathcal{M}_{\mathcal{PI}-\mathcal{EP}}\right) = \frac{p\left(D_T^C, D_T^{EP} | \mathcal{M}_{\mathcal{PI}-\mathcal{EP}}\right)}{p\left(D_T^{EP} | \mathcal{M}_{\mathcal{PI}-\mathcal{EP}}\right)}$$

while for the model with imperfect information and real-time data is:

$$p\left(D_T^C | D_T^{RT}, \mathcal{M}_{\mathcal{II}-\mathcal{RT}}\right) = \frac{p\left(D_T^C, D_T^{RT} | \mathcal{M}_{\mathcal{II}-\mathcal{RT}}\right)}{p\left(D_T^{RT} | \mathcal{M}_{\mathcal{II}-\mathcal{RT}}\right)}.$$

Finally, the conditional marginal data density of the model with perfect information and real-time data is:

$$p\left(D_T^C | D_T^{RT}, \mathcal{M}_{\mathcal{PI}-\mathcal{RT}}\right) = \frac{p\left(D_T^C, D_T^{RT} | \mathcal{M}_{\mathcal{PI}-\mathcal{RT}}\right)}{p\left(D_T^{RT} | \mathcal{M}_{\mathcal{PI}-\mathcal{RT}}\right)}$$

The conditional marginal data density:

$$p\left(D_T^C | D_T^{RT}, \mathcal{M}_{\mathcal{II}-\mathcal{RT}}\right) = \int p\left(D_T^C | \Theta, D_T^{RT}, \mathcal{M}_{\mathcal{II}-\mathcal{RT}}\right) p\left(\Theta | D_T^{RT}, \mathcal{M}_{\mathcal{II}-\mathcal{RT}}\right) d\Theta$$

where $p\left(D_T^C | \Theta, D_T^{RT}, \mathcal{M}_{\mathcal{II}-\mathcal{RT}}\right)$ is the conditional likelihood and $p\left(\Theta | D_T^{RT}, \mathcal{M}_{\mathcal{II}-\mathcal{RT}}\right)$ the conditional (on D_T^{RT}) distribution of the parameters Θ. A similar expression holds for the other two cases. The conditional marginal likelihood of, respectively, the $\mathcal{II}$-$\mathcal{RT}$, $\mathcal{PI}$-$\mathcal{EP}$ and $\mathcal{PI}$-$\mathcal{RT}$ models are equal to 354.44, 359.86 and 340.69. According to these numbers, there is ample evidence against the $\mathcal{PI}$-$\mathcal{RT}$ model. The difference between the marginal data density of the $\mathcal{II}$-$\mathcal{RT}$ and $\mathcal{PI}$-$\mathcal{EP}$ models is equal to 5.4 log points which suggests some, but although not strong, evidence in favour of the latter model. According to Jeffreys (1961) a difference between 2.3 and 4.6 would point to evidence in favor of the $\mathcal{PI}$-$\mathcal{EP}$ model while a higher threshold (6.9), used as forensic evidence in criminal case, is recommended by Evett (1991).

In addition to a formal evaluation of the empirical performance of the models, it is also useful to plot the median of the posterior distribution of the implied policy and inflation rates constructed using the smoothed estimates of the states of the models obtained with the Kalman smoother. For each draw from the posterior distribution of the parameters we draw 500 realizations of the state variables (from their normal distribution; see Hamilton, 1994, ch. 13) and then we compute the implied policy and inflation rates. Figures 4 and 5 report the median values of two variables together with the associated 0.90 confidence sets for the three models. The bottom right panel compares the median values. The figures allow us to get a more precise idea of the empirical performance of the models.

Figure 4 suggests that all the models capture the path of the policy rate. Only in two periods the actual rate falls outside the probability interval implied by the two models estimated with real-time data, regardless of the assumption on information.[18] According to these models, the peak of the tightening cycle would have been reached by the ECB in 2001 and not in 2000, as it actually happened (see the bottom right panel in Figure 4). The prescriptions of the $\mathcal{II}$-$\mathcal{RT}$ model also differ from the actual ECB's behaviour in the period 2006:Q4-2007:Q3 as the model suggests a pause in the tightening cycle that started at the end of 2005. The $\mathcal{PI}$-$\mathcal{EP}$ almost perfectly captures the actual path of the policy rate. The performance of the models changes radically with respect to inflation (see Figure 5). Indeed, the $\mathcal{PI}$-$\mathcal{EP}$ models has a very hard time in tracking actual inflation and attribute most of the short-run variability to measurement errors. The posterior median of the standard deviation of the measurement error in inflation is equal to 0.45 in the $\mathcal{PI}$-$\mathcal{EP}$ model and it falls to 0.29 and 0.31 per cent in the $\mathcal{II}$-$\mathcal{RT}$ and $\mathcal{PI}$-$\mathcal{RT}$ cases. The poor fit of the $\mathcal{PI}$-$\mathcal{EP}$ model also reflects the very small estimated slope of the hybrid NKPC (κ is equal to 0.007).[19]

4.3 Inflation and output gap stabilization trade-off

Next, we examine the monetary policy trade-off between inflation and output gap stabilization by constructing the so-called efficient policy frontier (see, Taylor, 1979). To this end, we first discretise the space spanned by the coefficients of the monetary policy rule, with the intervals $\phi_R \in [0.2, 0.8]$, $\phi_\pi \in [0.3, 2]$ and $\phi_x \in [0, 2]$. Then, after having controlled that the equilibrium under rational expectations is determinate, for each triplet $(\phi_R, \phi_\pi, \phi_x)$ we compute unconditional standard deviations of actual inflation (σ_π) and

[18] The marginally worse fit of the policy rate of the $\mathcal{II}$-$\mathcal{RT}$ model is due to the additional restrictions imposed by imperfect information on the dynamics of the variables and not by the presence of the indicator variables which play a role only in this model. If we estimate $\mathcal{II}$-$\mathcal{RT}$ model without the indicators, the fit of the policy rate actually worsen while the fit of inflation is still better than in the $\mathcal{PI}$-$\mathcal{EP}$ case.

[19] The model estimated in Lippi and Neri (2007) with ex-post revised data and imperfect information also features a very flat NKPC and has a hard time in accounting for the short-run fluctuations in inflation. The very low slope of the NKPC might depend on the fact that we allow (as Lippi and Neri, 2007) for measurement error in inflation. To test this hypothesis we have estimated both the $\mathcal{II}$-$\mathcal{RT}$ model and the $\mathcal{PI}$-$\mathcal{EP}$ fixing the standard deviation of the measurement error on inflation at zero. While the fit of inflation of the former model does not change at all, the performance of the latter model improves substantially. However, for the purpose of the paper, the main result concerning the policy trade-off faced by the ECB does not depend on the presence of the measurement error on inflation.

actual output gap (σ_x). The efficient frontier is defined as the locus of the lowest achievable pairs of (σ_π, σ_x). The frontier is expected to be negatively sloped as the opportunity cost in reducing output gap variability comes at the expense of greater inflation volatility. Note that for an accurate analysis of the monetary policy trade-off it is crucial to estimate the variances of the shocks and the measurement errors together with the parameters of the model as they jointly contribute to the shape and the location of the frontier.

An alternative way to compute the policy frontier, which would be more consistent with the Bayesian methodology used to estimate the models, would require re-estimating the posterior distribution of the parameters of the models for each combination of the parameters of the monetary policy rule and then computing the expected volatilities of inflation and the output gap.[20] While this approach is consistent with the Bayesian framework, it nevertheless complicates the interpretation of the results from a normative perspective. As for each triplet of the parameters of the policy rule the posterior distribution of the parameters of the model is re-estimated, it is not possible to attribute a given combination of volatilities of inflation and the output gap only to the specific policy rule as it also reflects, for example, the slope of the NKPC or the volatility or persistence of the shocks. Since the aim of this section is to characterize the set of monetary policies that would deliver the best combinations of inflation and output gap volatilities, we prefer to employ the first method and fix the parameters other than those characterizing monetary policy at the median of their posterior distribution.[21]

Figure 6 illustrates the results, organized in three panels each reporting the comparison of two models at a time. In particular, the blue, red and green lines depict the efficient frontier in the $\mathcal{II}$ -$\mathcal{RT}$, $\mathcal{PI}$-$\mathcal{EP}$ and $\mathcal{PI}$-$\mathcal{RT}$ models, respectively.[22] Several remarks are noteworthy. First, as indicated in panel A, moving from the standard $\mathcal{PI}$-$\mathcal{EP}$ to the more realistic $\mathcal{II}$-$\mathcal{RT}$ case, the efficient frontier shifts north-east. This indicates a deterioration of the monetary policy trade-off as the lowest attainable pairs of (σ_π, σ_x) under $\mathcal{PI}$-$\mathcal{EP}$ are not anymore so under $\mathcal{II}$-$\mathcal{RT}$. But, what does drive this result? To answer this question we reconstructed the efficient frontier under $\mathcal{II}$-$\mathcal{RT}$ by using one at a time the median estimates of the parameters obtained under $\mathcal{PI}$-$\mathcal{EP}$. It turns out that the outwards shift of the efficient frontier under $\mathcal{II}$-$\mathcal{RT}$ mainly reflects the increased estimated volatility of the cost-push shock, whose value is about more twice as big as that

[20] Denoting with S the pair of statistics (σ_x;σ_π) and with Θ_R the triplet of parameters (ϕ_R; ϕ_π; ϕ_x), the policy frontier would be defined as: $F = \min_{\Theta_R} \mathrm{E}\left[S|\Theta_R, Y_T\right]$.

[21] We have computed the policy frontier using the Bayesian approach for the $\mathcal{II}$-$\mathcal{RT}$ and the $\mathcal{PI}$-$\mathcal{EP}$ models. The results were qualitatively similar to those discussed in this section: the combinations of inflation and output gap volatilities in the model with perfect information would be unattainable in the more realistic case with imperfectly informed agents.

[22] Qualitative results would not change if one calculated the efficient frontier in terms of the standard deviations of filtered inflation ($\pi_{t|t}$) and output gap ($y_{t|t} - \overline{y}_{t|t}$).

under $\mathcal{PI}$-$\mathcal{EP}$. On this regard, it is worthwhile to recall that in our small-scale model only the cost-push shock implies a trade-off between inflation and output gap stabilisation. So, the higher the volatility of the cost-push shock the higher will be the values of σ_π and σ_x. To a less extent, also the increased estimated volatility of potential output under $\mathcal{II}$-$\mathcal{RT}$ contributes to the worsening of the trade-off. In this case, however, the rationale is different. Albeit under perfect information a shock to potential output does not imply a stabilisation trade-off, it may does so under imperfect information. Indeed, in this latter case when agents (including the central bank) estimate the state of the economy they will perceive that also a cost-push and a demand shock have occurred. Accordingly, the central bank will erroneously respond to these perceived shocks (and not to the actual shock) thus de-stabilise the economy.[23] Second, the overall shift of the efficient frontier depicted in panel A of Figure 6 can be decomposed into the distinct effects played by real-time data and by informational assumptions. Panel B compares the efficient frontier under $\mathcal{PI}$-$\mathcal{EP}$ and under $\mathcal{PI}$-$\mathcal{RT}$. Thus in line with the findings in Orphanides (2003), taking into account the real-time dimension of macroeconomic data deteriorates the monetary policy trade-off. Panel C shows instead the role of introducing imperfect information while keeping the same data set. Again moving from $\mathcal{PI}$-$\mathcal{RT}$ to $\mathcal{II}$-$\mathcal{RT}$ the efficient frontier further deteriorates. In both panels B and C the major driver underlying these successive outwards shifts of the frontier are the increased estimated volatilities of the cost-push shock and of potential output.[24] Third, it is interesting to see how the monetary policy rules estimated under $\mathcal{PI}$-$\mathcal{EP}$ and $\mathcal{II}$-$\mathcal{RT}$ perform with their respective efficient frontier.

As shown in panel A by the blue and red markers, in both cases the model evaluated at the median of the posterior distribution of the parameters deliver outcomes in terms of σ_{pi} and σ_x that could be improved upon. Indeed, the distance between these volatilities and the corresponding frontier is equal in the two cases suggesting that the potential gain from a more efficient policy is quantitatively similar in the two cases.

Overall, the policy implications in terms of efficient outcomes derived from a model characterized by perfect information and estimated using ex-post revised data are quite different from those that a model with imperfectly informed agents and estimated with real-time data would otherwise suggest. In particular, the outcomes in the $\mathcal{PI}$-$\mathcal{EP}$ case

[23] The efficient frontier is also sensitive to κ, the slope of the NKPC. This parameter is particular important for the conduct of monetary policy monetary policy as it determines the gain in reduced inflation per unit of negative output gap. In our case, under $\mathcal{II}$-$\mathcal{RT}$ the posterior median value of the NKPC slope is larger than that under $\mathcal{PI}$-$\mathcal{EP}$ thus suggesting an improvement in the trade-off. Changes in the other parameters do not seem to have a strong effect neither on the shape nor on the location of the efficient frontiers.

[24] The higher posterior median value of κ under $\mathcal{PI}$-$\mathcal{RT}$ and $\mathcal{II}$-$\mathcal{RT}$ the lower posterior median value of α under $\mathcal{PI}$-$\mathcal{RT}$ tend to improve the monetary policy trade-off. Again changes in the remaining estimated parameters barely affect the shape and location of the frontier.

would be unattainable in the more realistic $\mathcal{II}$-$\mathcal{RT}$ case and any attempt to direct the economy on that efficient locus might simply be unfeasible.

5 Concluding remarks

Monetary policy is inevitably conducted under conditions of great uncertainty about the underlying state of the economy and *without the benefit of hindsight.* Until recently, however, this fundamental as well as basic feature of actual policy-making has been largely overlooked in theoretical and empirical monetary analysis. Two recent advances for a more accurate analysis of monetary policy have been put forward by several authors. Attanasios Orphanides in a series of influential works has dealt with the issue of real-time vs. ex-post revised data for the evaluation of past monetary policy behaviour. Svensson and Woodford (2003) have introduced in otherwise standard microfounded general equilibrium models the assumption of imperfectly informed agents about the state of the economy.

This paper has been written with the purpose to bring together these two recent strands of research in a unifying empirical framework. In particular, we have estimated a small-scale New Keynesian model and examined the implications of imperfect information and real-time data for monetary policy. Our findings confirm the relevance of imperfect information and real-time data for monetary policy and show how their joint study further strengthen their implications. Our paper can be viewed as a warning as not to neglect in empirical analyses the inescapable features that characterize real time monetary policy-making as the ability of a central bank to achieve the best combination of inflation and output gap volatility depends critically on these features.

Finally, some caveats apply to our results. Although our preferred model is able to provide a correct description of actual monetary policy-making in the euro area, there is room for further improvements. One major improvement may regard the data revision process which in our framework is not explicitly modeled. Coenen et al. (2005) attempt to seriously mimic data revision by modelling a statistical agency that releases subsequent vintages of data. Introducing this modeling device into a small-scale theoretical model would then allow to use both real-time and ex-post revised data in the same estimation, paralleling the sequential information sets that are actually available as history unfolds. A potentially interesting and relevant avenue for future research would be to develop a deeper foundation of imperfect information and to use non-linear methods to solve the resulting model. These methods would allow for a stronger effect of uncertainty on monetary policy.

References

[1] Aoki, K. (2003), "On the optimal monetary policy response to noisy indicators", *Journal of Monetary Economics*, Vol. 50(3), pp. 501-253.

[2] Benati, L. (2008), "Investigating inflation persistence across monetary regimes", *Quarterly Journal of Economics*, Vol. 123(3), pp. 1005-1060.

[3] Boivin, J. and M. P. Giannoni (2006), "DGSE in a Data-Rich Environment", *mimeo*, HEC Montréal and Columbia University.

[4] Boivin, J. and M. P. Giannoni (2008), "Optimal Monetary Policy in a Data-Rich Environment", *mimeo*, HEC Montréal and Columbia University.

[5] Bomfim, A. (2001), "Measurement Error in General Equilibrium: The Aggregate Effects of Noisy Economic Indicator", *Journal of Monetary Economics*, Vol. 48, pp. 585-603.

[6] Christiano, L. J., M. Eichembaum and C. Evans (2005), "Nominal rigidities and the dynamic effects to a shock of monetary policy", *Journal of Political Economy*, Vol. 113(1), pp. 1-45.

[7] Clausen, J. R. and C. P. Meier (2005), "Did the Bundesbank follow a Taylor rule? An analysis based on real-time data", *Swiss Journal of Economics and Statistics*, Vol.127, pp. 213-246.

[8] Coenen, G., A. Levin and V. Wieland (2005), "Data uncertainty and the role of money as an information variable for monetary policy", *European Economic Review*, Vol. 49, pp. 975-1006.

[9] Collard, F. and H. Dellas (2010), "Monetary Misperceptions, Output, and Inflation Dynamics" *Journal of Money, Credit and Banking*, Vol. 42, No. 2-3, pp. 483-502.

[10] Collard, F., H. Dellas and F. Smets (2009), "Imperfect information and the business cycle", *Journal of Monetary Economics*, Vol. 56, Supplement 1, pp. 38-56.

[11] Croushore, D. forthcoming, "Frontiers of real-time data analysis", *Journal of Economic Literature.*

[12] Edge R. M., M. T. Kiley and J. Laforte (2009), "A Comparison of Forecast Performance Between Federal Reserve Staff Forecasts, Simple Reduced-Form Models, and a DSGE Model", Finance and Economics Discussion Series, Board of Governors of the Federal Reserve.

[13] Ehrmann, M. and F. Smets (2003), "Uncertain potential output: implications for monetary policy", *Journal of Economic Dynamics and Control*, Vol. 27, pp. 1611-38.

[14] Evett, I. W. (1991), "Implementing Bayesian methods in forensic science ", Paper presented at the Fourth Valencia International Meeting on Bayesian Statistics

[15] Fernańdez-Villaverde J. and J. F. Rubio-Rammírez (2004), "Comparing dynamic equilibrium models to data: a Bayesian approach", *Journal of Econometrics*, Vol. 123, pp. 153-187.

[16] Fuhrer, J. C. and G. Moore (1995), "Inflation persistence policy", *Quarterly Journal of Economics*, Vol. 110, pp. 127-160

[17] Galí J. and M. Gertler (1999), "Inflation dynamics: a structural econometric analysis", *Journal of Monetary Economics*, Vol. 44 (2), pp. 195-222.

[18] Gerdesmeier, D. and B. Roffia (2005), "The relevance of real-time data in estimating reaction functions for the euro area", *North American Journal of Economics and Finance*, Vol. 16, pp. 293-307.

[19] Geweke, J. (1999), "Using simulation methods for bayesian econometric models: inference, development,and communication", *Econometric Reviews*, Vol. 18(1), pp. 1-73.

[20] Giannone, D., J. Henry, M. Lalik and M. Modugno (2010), "An area-wide real-time database for the euro area", European Central Bank, Working Paper Series, No. 1145.

[21] Hamilton, J. D. (1994): Time Series Analysis. Princeton University Press, Princeton, NJ.

[22] Ireland, P. (2001), "Sticky price models of the business cycle: specification and stability", *Journal of Monetary Economics*, Vol. 47(1), pp. 3-18.

[23] Jeffreys, H. (1961), Theory of Probability (3rd ed.), Oxford, U.K.: Oxford University Press.

[24] Kilponen, J. (2004), "Robust expectations and uncertain models - A robust control approach with application to the New Keynesian economy", Bank of Finland, Research Discussion Papers, 5/2004.

[25] Kolasa M., M. Rubaszek and P. Skrzypczyński (2009), "Putting the New Keynesian DSGE model to the real-time forecasting test", Working Paper Series No. 1110, European Central Bank.

[26] Koske I. and Pain N. (2008), "The usefulness of output gaps for policy analysis", OECD Working Papers No. 621.

[27] Kozicki, S. (2004), "How do data revisions affect the evaluation and conduct of monetary policy?", Federal Reserve Bank of Kansas City. Economic Review, pp. 5-38.

[28] Laubach, T. and J. C. Williams (2003), "Measuring the Natural Rate of Interest", *The Review of Economics and Statistics*, Vol. 85(4), pp. 1063-1070.

[29] Levine, P., J. Pearlman, G. Perendia and B. Yang (2010), "Endogenous Persistence in an Estimated DSGE Model under Imperfect Information", Centre for Dynamic Macroeconomic Analysis Working Paper Series, No. 10/02.

[30] Lippi, F. and S. Neri (2005), "Information variables for monetary policy in an estimated structural model of the euro area", Temi di discussione, Banca d'Italia, No. 511.

[31] Lippi, F. and S. Neri (2007), "Information variables for monetary policy in an estimated structural model of the euro area", *Journal of Monetary Economics*, Vol. 54, pp. 1256-1270.

[32] Orphanides, A. (2001), "Monetary Policy Rules Based on Real-Time Data", *The American Economic Review*, Vol. 91(4), pp. 964-985.

[33] Orphanides, A. (2003), "Monetary policy evaluation with noisy information", *Journal of Monetary Economics*, Vol. 50, pp. 605–631.

[34] Orphanides, A. and J. Williams (2002), "Robust Monetary Policy Rules with Unknown Natural Rates", *Brookings Papers on Economic Activity*, Vol. 2 , pp. 63-118.

[35] Orphanides, A. and J. Williams (2007), "Robust monetary policy with imperfect knowledge", *Journal of Monetary Economics*, Vol. 54(5) , pp. 1406-1435.

[36] Pearlman, J. G., D. Currie and P. Levine (1986), "Rational expectations models with partial information", *Economic Modelling*, Vol. 3, pp. 90-105.

[37] Rabanal, P. and J. F. Rubio-Ramírez (2005), "Comparing New Keynesian Models of the Business Cycle: A Bayesian Approach", *Journal of Monetary Economics*, Vol. 52(6) , pp. 1151-1166.

[38] Smets, F. (2003), "Maintaining price stability: how long is the medium term?", *Journal of Monetary Economics*, Vol. 50(6), pp. 1123-1175.

[39] Smets, F. and R. Wouters (2003), "An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area", *Journal of the European Economic Association*, Vol. 1(5), pp. 1293-1309.

[40] Svensson, L. O. E. and M. Woodford (2003), "Indicator variables for optimal policy", *Journal of Monetary Economics*, Vol. 50, pp. 691-720.

[41] Taylor, J. B. (1979), "Estimation and Control of a Macroeconomic Model with Rational Expectations", *Econometrica*, Vol. 47(5), pp. 1267-1286.

[42] Uhlig, H. (1999), "A Toolkit for Analysing Nonlinear Dynamic Stochastic Models Easily", in R. Marimon and A. Scott: Computational Methods for the Study of Dynamic Economies. Oxford and New York: Oxford University Press.

[43] Woodford, M. (2003), Interest and prices - Foundations of a Theory of Monetary Policy, Princeton University Press, Princeton, NJ.

Tables and figures

Table 2. Data and sources

model counterpart	Real-time (RT)	Ex-post revised (EP)
core variables		
y_t	Real GDP: EABCN	Real GDP: Eurostat
$y_t - \overline{y}_t$	Output gap: IMF, OECD	Output gap: IMF, OECD
π_t^{year}	HICP: Eurostat	HICP: Eurostat
r_t	Minimum bid rate: European Central Bank	Minimum bid rate: European Central Bank
non-core variables		
$y_t - y_{t-1}$	€-coin: CEPR-Banca d'Italia	€-coin: CEPR-Banca d'Italia
$y_t - y_{t-1}$	PMI: Markit Economics	PMI: Markit Economics
$\pi_{t+1\|t}^{year}$	Inflation expectations: Consensus Economics	Inflation expectations: Consensus Economics

Note: PMI refers to Purchasing Managers' Index.

Table 3. Summary statistics for the prior distribution of the parameters

Parameter	Type	Support	Mean	Std. Dev.	2.5%	50%	97.5%
α	Beta	[0,1)	0.5	0.1	0.306	0.500	0.694
δ	Beta	[0,1)	0.5	0.1	0.306	0.500	0.694
θ	Gamma	$\Re^+$	0.25	0.1	0.094	0.237	0.480
κ	Gamma	$\Re^+$	0.1	0.05	0.027	0.092	0.219
ϕ_R	Beta	[0,1)	0.5	0.1	0.324	0.493	0.714
ϕ_π	Gamma	$\Re^+$	0.5	0.1	0.303	0.500	0.696
ϕ_x	Normal	$\Re$	0.5	0.1	0.305	0.500	0.694
ρ_c	Beta	[0,1)	0.7	0.1	0.488	0.707	0.874
ρ_d	Beta	[0,1)	0.7	0.1	0.488	0.707	0.874
$\rho_{\overline{y}}$	Beta	[0,1)	0.1	0.1	0.488	0.707	0.874
σ_c^u	Gamma	$\Re^+$	1.0	0.5	0.270	0.920	2.190
σ_d^u	Gamma	$\Re^+$	1.0	0.5	0.270	0.920	2.190
$\sigma_{\overline{y}}^u$	Gamma	$\Re^+$	1.0	0.5	0.270	0.920	2.190
σ_x^u	Gamma	$\Re^+$	1.0	0.5	0.270	0.920	2.190
σ_e^u	Gamma	$\Re^+$	1.0	0.5	0.270	0.920	2.190
σ_{pm}^u	Gamma	$\Re^+$	1.0	0.5	0.270	0.920	2.190
σ_y^u	Gamma	$\Re^+$	1.0	0.5	0.270	0.920	2.190
$\sigma_{\pi^e}^u$	Gamma	$\Re^+$	1.0	0.5	0.270	0.920	2.190
σ_π^u	Gamma	$\Re^+$	1.0	0.5	0.270	0.920	2.190
σ_R	Gamma	$\Re^+$	1.0	0.5	0.270	0.920	2.190

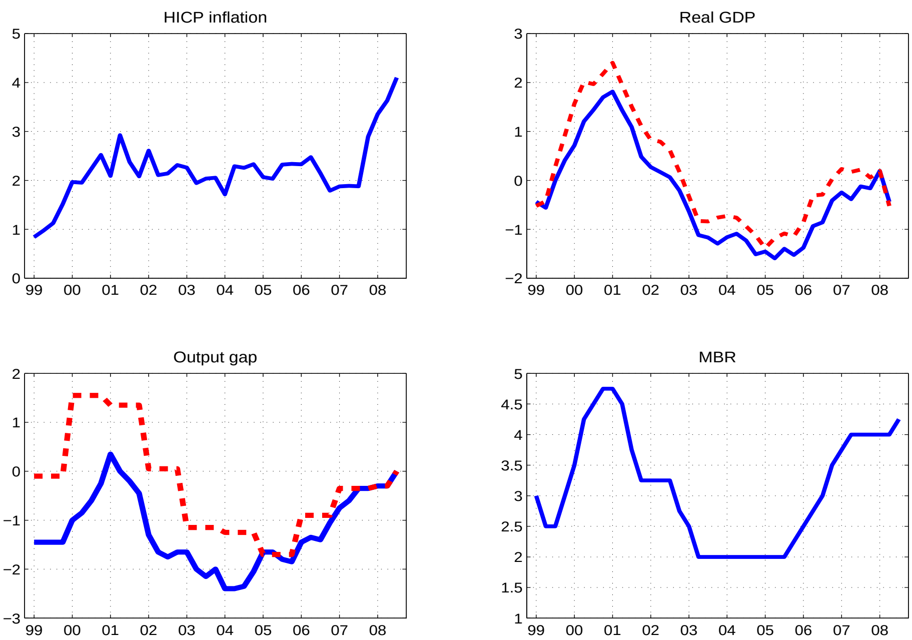
Note: Statistics for the standard deviations (σ's) are in percentage points.

Table 4. Summary statistics of the posterior distribution of the parameters

	Prior	$\mathcal{PI}$-$\mathcal{EP}$			$\mathcal{II}$-$\mathcal{RT}$			$\mathcal{PI}$-$\mathcal{RT}$		
	50%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
α	0.500	0.091	0.160	0.252	0.088	0.157	0.245	0.089	0.155	0.242
δ	0.500	0.506	0.614	0.751	0.502	0.596	0.711	0.492	0.609	0.744
θ	0.237	0.125	0.260	0.470	0.146	0.290	0.487	0.127	0.260	0.466
κ	0.092	0.002	0.007	0.023	0.004	0.015	0.051	0.003	0.010	0.026
ϕ_π	0.493	0.361	0.470	0.618	0.253	0.309	0.447	0.251	0.284	0.394
ϕ_x	0.500	0.131	0.171	0.211	0.173	0.232	0.289	0.221	0.291	0.379
ϕ_R	0.500	0.217	0.347	0.484	0.292	0.454	0.635	0.244	0.390	0.602
ρ_c	0.707	0.459	0.669	0.831	0.373	0.559	0.728	0.345	0.540	0.738
ρ_d	0.707	0.646	0.769	0.867	0.647	0.770	0.864	0.641	0.766	0.865
$\rho_{\overline{y}}$	0.707	0.500	0.709	0.865	0.714	0.827	0.915	0.717	0.844	0.929
σ_c^u	0.900	0.009	0.024	0.057	0.030	0.059	0.109	0.019	0.048	0.106
σ_d^u	0.900	0.036	0.062	0.105	0.046	0.064	0.091	0.035	0.061	0.101
$\sigma_{\overline{y}}^u$	0.900	0.054	0.125	0.225	0.225	0.300	0.409	0.158	0.239	0.354
σ_x^u	0.900	0.221	0.293	0.403	0.042	0.114	0.236	0.079	0.425	0.594
σ_e^u	0.900	0.039	0.065	0.099	0.052	0.079	0.111	0.047	0.071	0.102
σ_{pm}^u	0.900	0.023	0.030	0.042	0.017	0.024	0.033	0.018	0.025	0.035
σ_y^u	0.900	0.161	0.217	0.295	0.136	0.173	0.227	0.104	0.137	0.185
$\sigma_{\pi^e}^u$	0.900	0.223	0.294	0.390	0.182	0.252	0.343	0.173	0.238	0.334
σ_π^u	0.900	0.341	0.446	0.581	0.207	0.287	0.404	0.215	0.313	0.452
σ_R	0.900	0.010	0.023	0.056	0.073	0.101	0.144	0.010	0.028	0.152

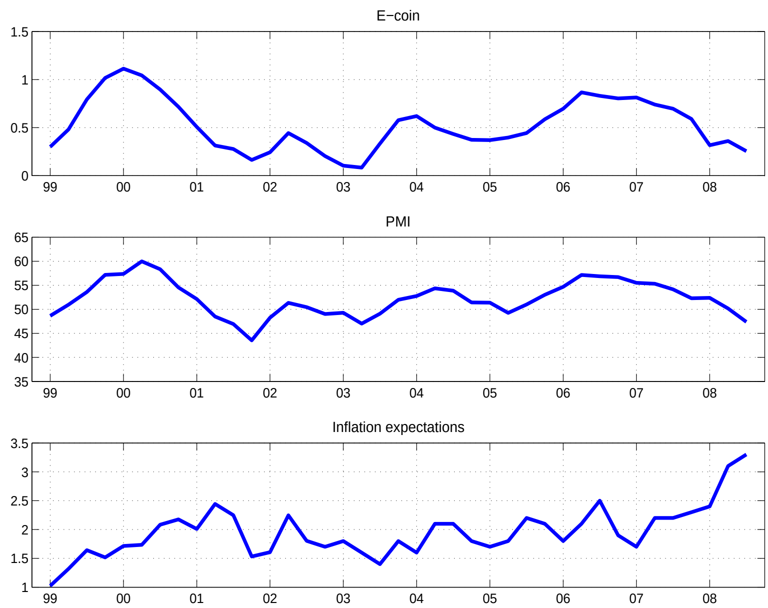
Note: The results are based 5 parallel chains, each of length 250,000 draws, generated with the Metropolis algorithm. $\mathcal{II}$-$\mathcal{RT}$: model with imperfect information and real-time data; $\mathcal{PI}$-$\mathcal{RT}$: model with perfect information and real-time data; $\mathcal{PI}$-$\mathcal{EP}$: model with perfect information and ex-post revised data. Statistics for the standard deviations (σ's) are in percentage points.

Figure 1a - Data



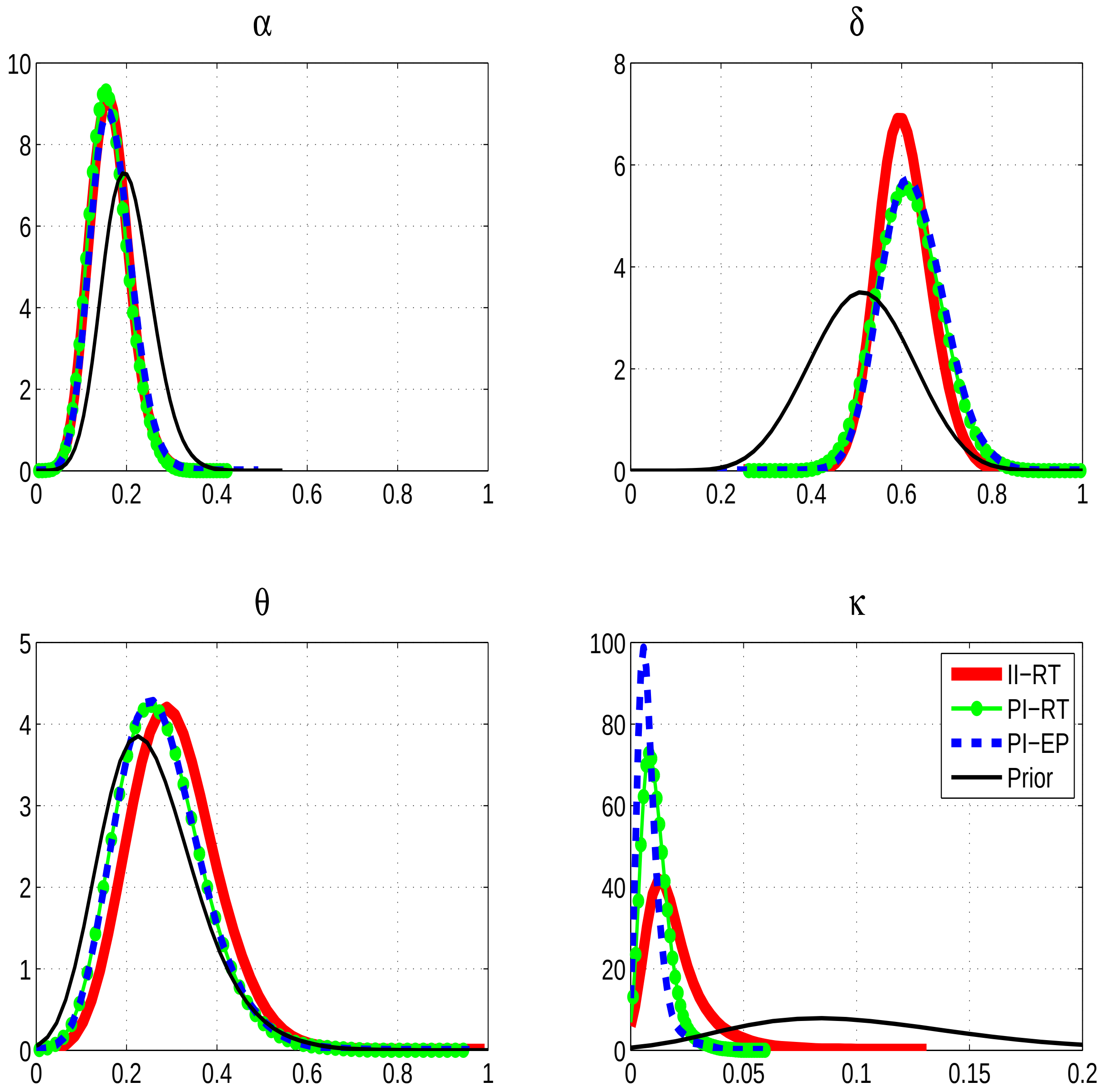
Note: For real GDP, the output gap and real GDP growth we report the real-time data (blue solid line) and the ex-post revised data (red dashed line); MBR = minimum bid rate

Figure 1b - Data



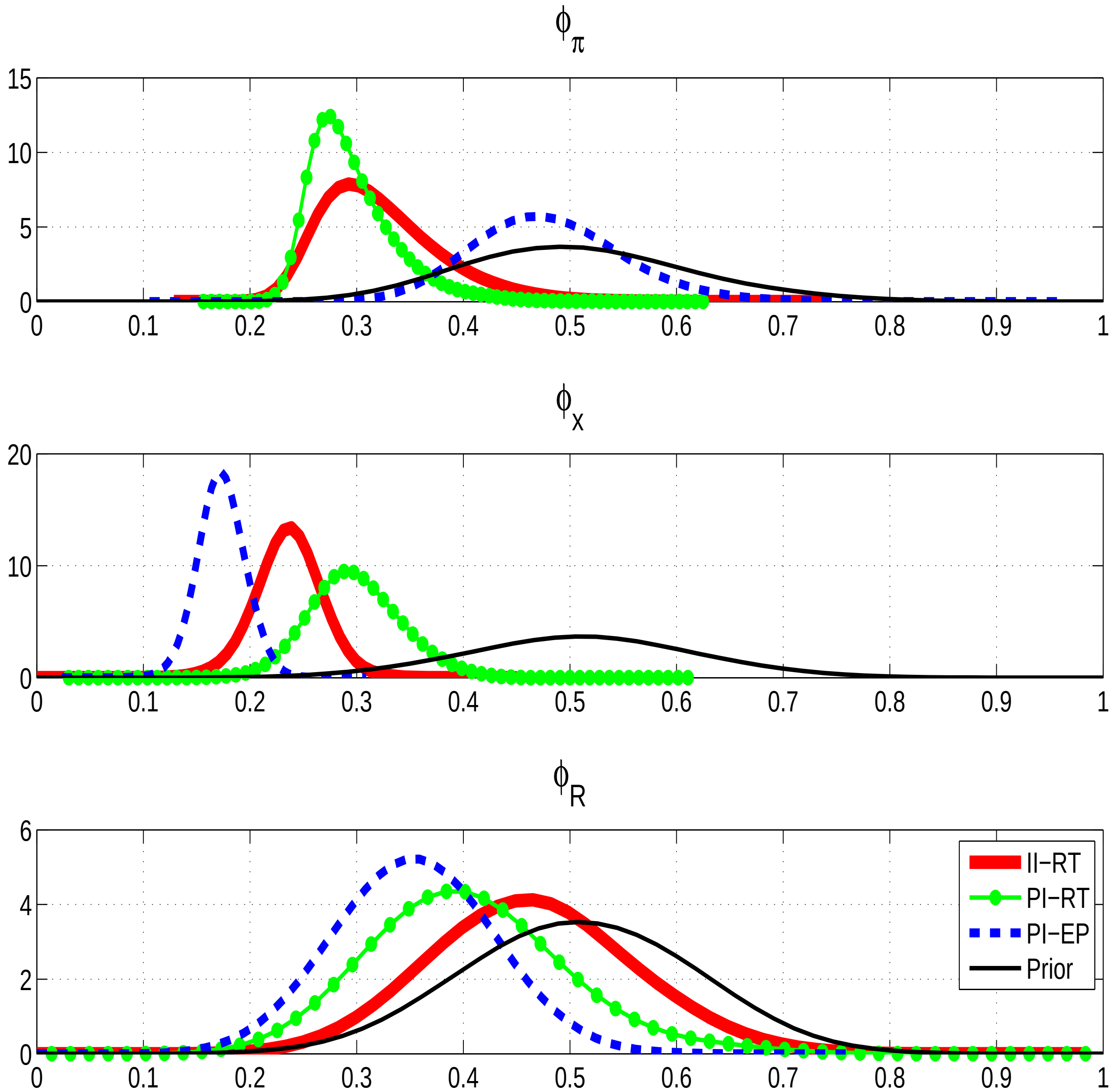
Note: PMI: Purchasing Managers' Index

Figure 2 - Prior and posterior marginal distributions



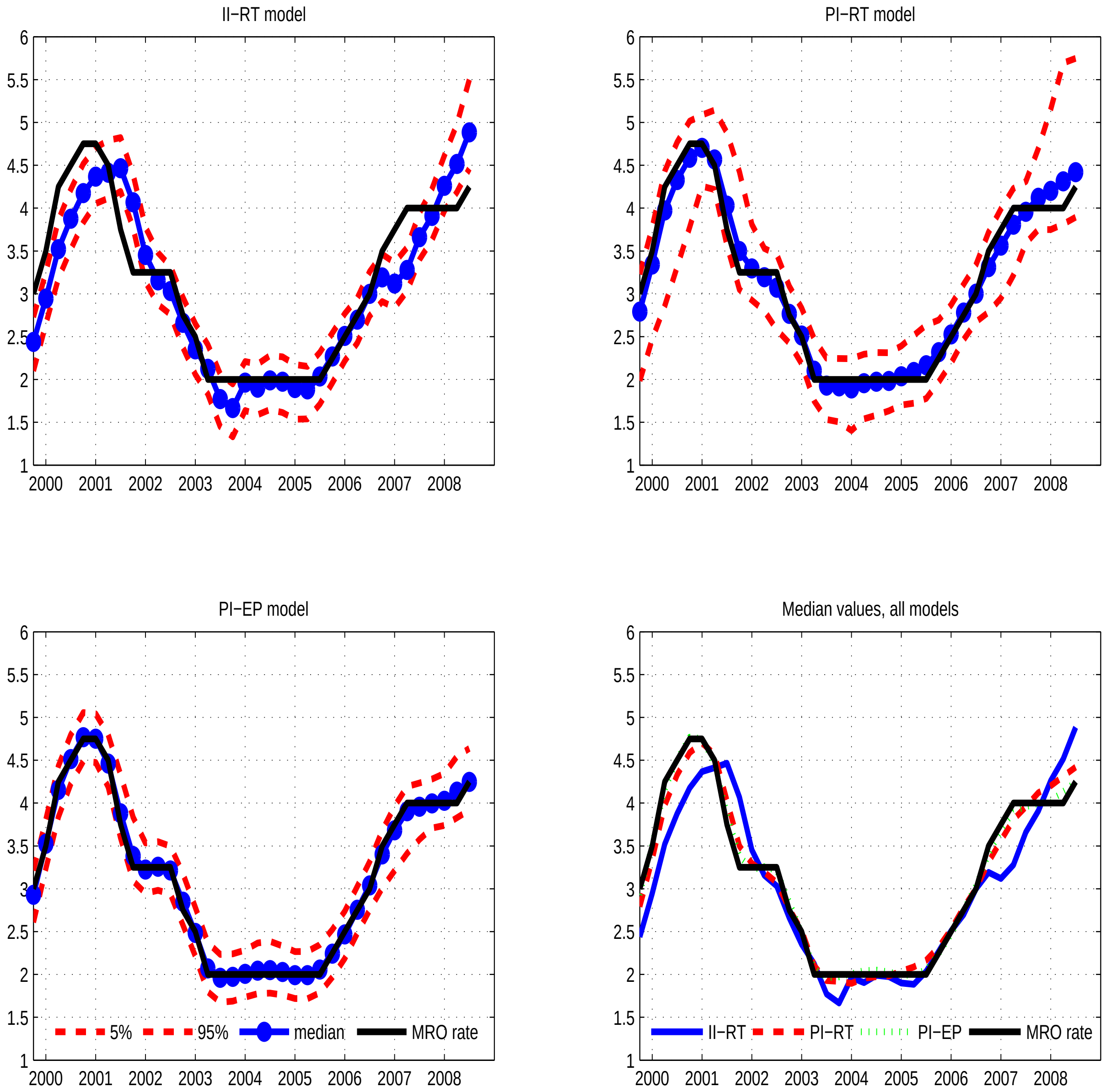
Note: The marginal posterior distributions are computed using 5 chains each of length 250,00 draws from the Metropolis algorithm. The red solid line refers to the model with imperfect information and real-time data ($\mathcal{II}$-$\mathcal{RT}$); the blue dashed line to the model with perfect information and ex-post revised data ($\mathcal{PI}$-$\mathcal{EP}$); the green line with dots to the model with perfect information and real-time data; the black thin solid line denotes the prior density.

Figure 3 - Prior and posterior marginal distributions



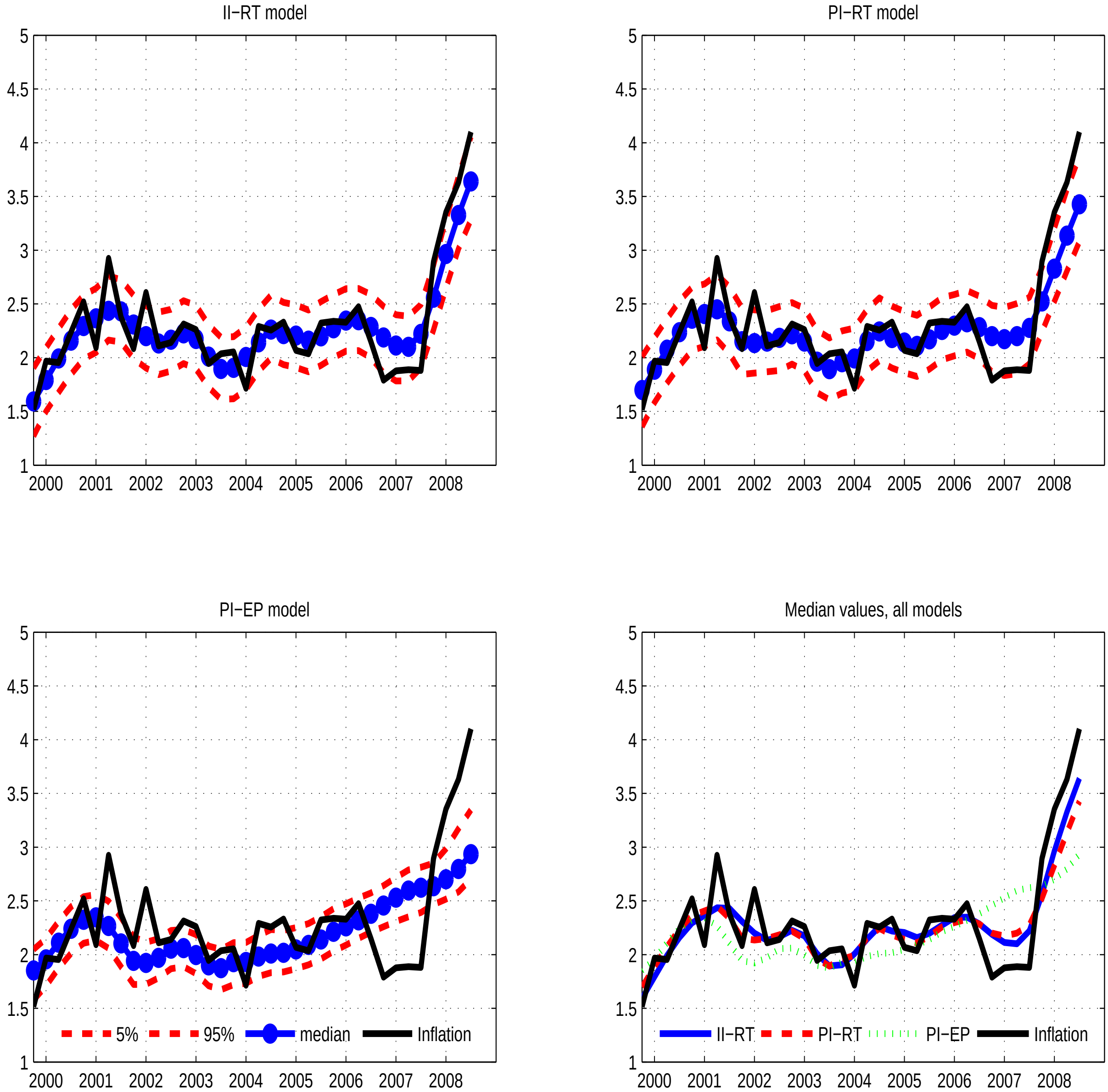
Note: The marginal posterior distributions are computed using 5 chains each of length 250,00 draws from the Metropolis algorithm. The red solid line refers to the model with imperfect information and real-time data ($\mathcal{II}$-$\mathcal{RT}$); the blue dashed line to the model with perfect information and ex-post revised data ($\mathcal{PI}$-$\mathcal{EP}$); the green line with dots to the model with perfect information and real-time data; the black thin solid line denotes the prior density.

Figure 4 - Fit of the minimum bid rate (MBR)



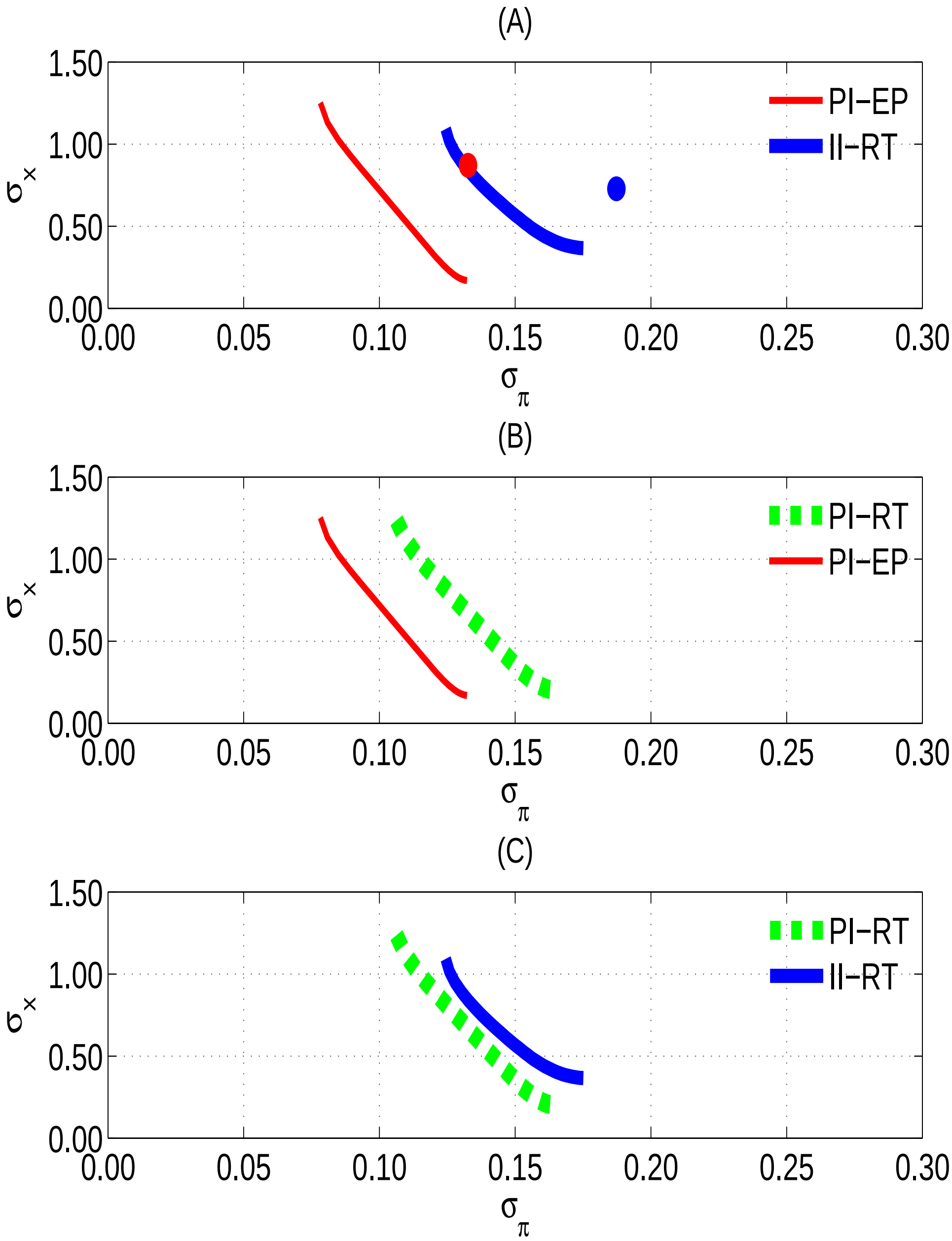
Note: $\mathcal{II}$-$\mathcal{RT}$ denotes the model with imperfect information and real-time data; $\mathcal{PI}$-$\mathcal{EP}$ denotes the model with perfect information and revised data; $\mathcal{PI}$-$\mathcal{RT}$ denotes the model with perfect information and real-time data. The fitted values are computed using the median of the posterior distributions of the parameters. Red dashed lines denote the 0.90 probability intervals.

Figure 5 - Fit of the inflation rate



Note: $\mathcal{II}$-$\mathcal{RT}$ denotes the model with imperfect information and real-time data; $\mathcal{PI}$-$\mathcal{EP}$ denotes the model with perfect information and revised data; $\mathcal{PI}$-$\mathcal{RT}$ denotes the model with perfect information and real-time data. The fitted values are computed using the median of the posterior distributions of the parameters. Red dashed lines denote the 0.90 probability intervals.

Figure 6 - Output gap - inflation volatility frontier



Note: $\mathcal{II}$-$\mathcal{RT}$ stands for imperfect information and real-time data, $\mathcal{PI}$-$\mathcal{RT}$ for perfect information and real-time data and $\mathcal{PI}$-$\mathcal{EP}$ for perfect information and revised data. The frontiers are computed by varying the parameters of the Taylor rule, ϕ_R, ϕ_x and ϕ_π, while keeping all the other parameters fixed at the median of their marginal posterior distributions. The blue and red dots refers to the volatilities of inflation and the output gap implied by, respectively, the $\mathcal{PI}$-$\mathcal{RT}$ and $\mathcal{PI}$-$\mathcal{EP}$ models solved using the median of the posterior distribution of the parameters.

RECENTLY PUBLISHED "TEMI" (*)

N. 776 – *Measuring the price elasticity of import demand in the destination markets of Italian exports*, by Alberto Felettigh and Stefano Federico (October 2010).

N. 777 – *Income reporting behaviour in sample surveys*, by Andrea Neri and Roberta Zizza (October 2010).

N. 778 – *The rise of risk-based pricing of mortgage interest rates in Italy*, by Silvia Magri and Raffaella Pico (October 2010).

N. 779 – *On the interaction between market and credit risk: a factor-augmented vector autoregressive (FAVAR) approach*, by Roberta Fiori and Simonetta Iannotti (October 2010).

N. 780 – *Under/over-valuation of the stock market and cyclically adjusted earnings*, by Marco Taboga (December 2010).

N. 781 – *Changing institutions in the European market: the impact on mark-ups and rents allocation*, by Antonio Bassanetti, Roberto Torrini and Francesco Zollino (December 2010).

N. 782 – *Central bank's macroeconomic projections and learning*, by Giuseppe Ferrero and Alessandro Secchi (December 2010).

N. 783 – *(Non)persistent effects of fertility on female labour supply*, by Concetta Rondinelli and Roberta Zizza (December 2010).

N. 784 – *Stars and comets: an exploration of the patent universe* , by Carlo Menon (January 2011).

N. 785 – *Sectoral money demand and the great disinflation in the US*, by Alessandro Calza and Andrea Zaghini (January 2011).

N. 786 – *Public sector efficiency and political culture* , by Raffaela Giordano and Pietro Tommasino (January 2011).

N. 787 – *Monetary incentives vs. monitoring in addressing absenteeism: experimental evidence*, by Francesco D'Amuri (January 2011).

N. 788 – *FaMIDAS: A Mixed Frequency Factor Model with MIDAS structure*, by Cecilia Frale and Libero Monteforte (January 2011).

N. 789 – *Policies for local development: an evaluation of Italy's "Patti Territoriali"*, by Antonio Accetturo and Guido de Blasio (January 2011).

N. 790 – *Testing for east-west contagion in the European banking sector during the financial crisis*, by Emidio Cocozza and Paolo Piselli (February 2011).

N. 791 – *Are incentives for R&D effective? Evidence from a regression discontinuity approach*, by Raffaello Bronzini and Eleonora Iachini (February 2011).

N. 792 – *Evaluating the impact of innovation incentives: evidence from an unexpected shortage of funds*, by Guido de Blasio, Davide Fantino and Guido Pellegrini (February 2011).

N. 793 – *Credit availability and investment in italy: lessons from the "Great Recession"*, by Eugenio Gaiotti (February 2011).

N. 794 – *Bridging the gap between migrants and the banking system*, by Giorgio Albareto and Paolo Emilio Mistrulli (February 2011).

N. 795 – *I fondi comuni aperti in italiaItalia: performance delle societa'società di gestione del risparmio*, by Michele Leonardo Bianchi and Maria Grazia Miele (February 2011).

N. 796 – *Securitization is not that evil after all*, by Ugo Albertazzi, Ginette Eramo, Leonardo Gambacorta and Carmelo Salleo (February 2011).

(*) Requests for copies should be sent to:
Banca d'Italia – Servizio Studi di struttura economica e finanziaria – Divisione Biblioteca e Archivio storico – Via Nazionale, 91 – 00184 Rome – (fax 0039 06 47922059). They are available on the Internet www.bancaditalia.it.

2008

P. ANGELINI, *Liquidity and announcement effects in the euro area*, Giornale degli Economisti e Annali di Economia, v. 67, 1, pp. 1-20, **TD No. 451 (October 2002).**

P. ANGELINI, P. DEL GIOVANE, S. SIVIERO and D. TERLIZZESE, *Monetary policy in a monetary union: What role for regional information?*, International Journal of Central Banking, v. 4, 3, pp. 1-28, **TD No. 457 (December 2002).**

F. SCHIVARDI and R. TORRINI, *Identifying the effects of firing restrictions through size-contingent Differences in regulation*, Labour Economics, v. 15, 3, pp. 482-511, **TD No. 504 (June 2004).**

L. GUISO and M. PAIELLA,, *Risk aversion, wealth and background risk*, Journal of the European Economic Association, v. 6, 6, pp. 1109-1150, **TD No. 483 (September 2003).**

C. BIANCOTTI, G. D'ALESSIO and A. NERI, *Measurement errors in the Bank of Italy's survey of household income and wealth*, Review of Income and Wealth, v. 54, 3, pp. 466-493, **TD No. 520 (October 2004).**

S. MOMIGLIANO, J. HENRY and P. HERNÁNDEZ DE COS, *The impact of government budget on prices: Evidence from macroeconometric models*, Journal of Policy Modelling, v. 30, 1, pp. 123-143 **TD No. 523 (October 2004).**

L. GAMBACORTA, *How do banks set interest rates?,* European Economic Review, v. 52, 5, pp. 792-819, **TD No. 542 (February 2005).**

P. ANGELINI and A. GENERALE, *On the evolution of firm size distributions*, American Economic Review, v. 98, 1, pp. 426-438, **TD No. 549 (June 2005).**

R. FELICI and M. PAGNINI, *Distance, bank heterogeneity and entry in local banking markets,* The Journal of Industrial Economics, v. 56, 3, pp. 500-534, **No. 557 (June 2005).**

S. DI ADDARIO and E. PATACCHINI, *Wages and the city. Evidence from Italy*, Labour Economics, v.15, 5, pp. 1040-1061, **TD No. 570 (January 2006).**

S. SCALIA, *Is foreign exchange intervention effective?,* Journal of International Money and Finance, v. 27, 4, pp. 529-546, **TD No. 579 (February 2006).**

M. PERICOLI and M. TABOGA, *Canonical term-structure models with observable factors and the dynamics of bond risk premia,* Journal of Money, Credit and Banking, v. 40, 7, pp. 1471-88, **TD No. 580 (February 2006).**

E. VIVIANO, *Entry regulations and labour market outcomes. Evidence from the Italian retail trade sector*, Labour Economics, v. 15, 6, pp. 1200-1222, **TD No. 594 (May 2006).**

S. FEDERICO and G. A. MINERVA, *Outward FDI and local employment growth in Italy,* Review of World Economics, Journal of Money, Credit and Banking, v. 144, 2, pp. 295-324, **TD No. 613 (February 2007).**

F. BUSETTI and A. HARVEY, *Testing for trend*, Econometric Theory, v. 24, 1, pp. 72-87, **TD No. 614 (February 2007).**

V. CESTARI, P. DEL GIOVANE and C. ROSSI-ARNAUD, *Memory for prices and the Euro cash changeover: an analysis for cinema prices in Italy*, In P. Del Giovane e R. Sabbatini (eds.), The Euro Inflation and Consumers' Perceptions. Lessons from Italy, Berlin-Heidelberg, Springer, **TD No. 619 (February 2007).**

B. H. HALL, F. LOTTI and J. MAIRESSE, *Employment, innovation and productivity: evidence from Italian manufacturing microdata*, Industrial and Corporate Change, v. 17, 4, pp. 813-839, **TD No. 622 (April 2007).**

J. SOUSA and A. ZAGHINI, *Monetary policy shocks in the Euro Area and global liquidity spillovers,* International Journal of Finance and Economics, v.13, 3, pp. 205-218, **TD No. 629 (June 2007).**

M. DEL GATTO, GIANMARCO I. P. OTTAVIANO and M. PAGNINI, *Openness to trade and industry cost dispersion: Evidence from a panel of Italian firms,* Journal of Regional Science, v. 48, 1, pp. 97-129, **TD No. 635 (June 2007).**

P. DEL GIOVANE, S. FABIANI and R. SABBATINI, *What's behind "inflation perceptions"? A survey-based analysis of Italian consumers,* in P. Del Giovane e R. Sabbatini (eds.), *The Euro Inflation and Consumers' Perceptions. Lessons from Italy,* Berlin-Heidelberg, Springer, **TD No. 655 (January 2008).**

R. BRONZINI, G. DE BLASIO, G. PELLEGRINI and A. SCOGNAMIGLIO, *La valutazione del credito d'imposta per gli investimenti*, Rivista di politica economica, v. 98, 4, pp. 79-112, **TD No. 661 (April 2008).**

B. BORTOLOTTI, and P. PINOTTI, *Delayed privatization,* Public Choice, v. 136, 3-4, pp. 331-351, **TD No. 663 (April 2008).**

R. BONCI and F. COLUMBA, *Monetary policy effects: New evidence from the Italian flow of funds,* Applied Economics , v. 40, 21, pp. 2803-2818, **TD No. 678 (June 2008).**

M. CUCCULELLI, and G. MICUCCI, *Family Succession and firm performance: evidence from Italian family firms,* Journal of Corporate Finance, v. 14, 1, pp. 17-31, **TD No. 680 (June 2008).**

A. SILVESTRINI and D. VEREDAS, *Temporal aggregation of univariate and multivariate time series models: a survey,* Journal of Economic Surveys, v. 22, 3, pp. 458-497, **TD No. 685 (August 2008).**

2009

F. PANETTA, F. SCHIVARDI and M. SHUM, *Do mergers improve information? Evidence from the loan market,* Journal of Money, Credit, and Banking, v. 41, 4, pp. 673-709, **TD No. 521 (October 2004).**

M. BUGAMELLI and F. PATERNÒ, *Do workers' remittances reduce the probability of current account reversals?,* World Development, v. 37, 12, pp. 1821-1838, **TD No. 573 (January 2006).**

P. PAGANO and M. PISANI, *Risk-adjusted forecasts of oil prices*, The B.E. Journal of Macroeconomics, v. 9, 1, Article 24, **TD No. 585 (March 2006).**

M. PERICOLI and M. SBRACIA, *The CAPM and the risk appetite index: theoretical differences, empirical similarities, and implementation problems,* International Finance, v. 12, 2, pp. 123-150, **TD No. 586 (March 2006).**

U. ALBERTAZZI and L. GAMBACORTA, *Bank profitability and the business cycle,* Journal of Financial Stability, v. 5, 4, pp. 393-409, **TD No. 601 (September 2006).**

S. MAGRI, *The financing of small innovative firms: the Italian case,* Economics of Innovation and New Technology, v. 18, 2, pp. 181-204, **TD No. 640 (September 2007).**

V. DI GIACINTO and G. MICUCCI, *The producer service sector in Italy: long-term growth and its local determinants,* Spatial Economic Analysis, Vol. 4, No. 4, pp. 391-425, **TD No. 643 (September 2007).**

F. LORENZO, L. MONTEFORTE and L. SESSA, *The general equilibrium effects of fiscal policy: estimates for the euro area*, Journal of Public Economics, v. 93, 3-4, pp. 559-585, **TD No. 652 (November 2007).**

R. GOLINELLI and S. MOMIGLIANO, *The Cyclical Reaction of Fiscal Policies in the Euro Area. A Critical Survey of Empirical Research*, Fiscal Studies, v. 30, 1, pp. 39-72, **TD No. 654 (January 2008).**

P. DEL GIOVANE, S. FABIANI and R. SABBATINI, *What's behind "Inflation Perceptions"? A survey-based analysis of Italian consumers,* Giornale degli Economisti e Annali di Economia, v. 68, 1, pp. 25-52, **TD No. 655 (January 2008).**

F. MACCHERONI, M. MARINACCI, A. RUSTICHINI and M. TABOGA, *Portfolio selection with monotone mean-variance preferences,* Mathematical Finance, v. 19, 3, pp. 487-521, **TD No. 664 (April 2008).**

M. AFFINITO and M. PIAZZA, *What are borders made of? An analysis of barriers to European banking integration,* in P. Alessandrini, M. Fratianni and A. Zazzaro (eds.): The Changing Geography of Banking and Finance, Dordrecht Heidelberg London New York, Springer, **TD No. 666 (April 2008).**

A. BRANDOLINI, *On applying synthetic indices of multidimensional well-being: health and income inequalities in France, Germany, Italy, and the United Kingdom,* in R. Gotoh and P. Dumouchel (eds.), Against Injustice. The New Economics of Amartya Sen, Cambridge, Cambridge University Press, **TD No. 668 (April 2008).**

G. FERRERO and A. NOBILI, *Futures contract rates as monetary policy forecasts,* International Journal of Central Banking, v. 5, 2, pp. 109-145, **TD No. 681 (June 2008).**

P. CASADIO, M. LO CONTE and A. NERI, *Balancing work and family in Italy: the new mothers' employment decisions around childbearing,* in T. Addabbo and G. Solinas (eds.), Non-Standard Employment and Qualità of Work, Physica-Verlag. A Sprinter Company, **TD No. 684 (August 2008).**

L. ARCIERO, C. BIANCOTTI, L. D'AURIZIO and C. IMPENNA, *Exploring agent-based methods for the analysis of payment systems: A crisis model for StarLogo TNG,* Journal of Artificial Societies and Social Simulation, v. 12, 1, **TD No. 686 (August 2008).**

A. CALZA and A. ZAGHINI, *Nonlinearities in the dynamics of the euro area demand for M1,* Macroeconomic Dynamics, v. 13, 1, pp. 1-19, **TD No. 690 (September 2008).**

L. FRANCESCO and A. SECCHI, *Technological change and the households' demand for currency,* Journal of Monetary Economics, v. 56, 2, pp. 222-230, **TD No. 697 (December 2008).**

G. ASCARI and T. ROPELE, *Trend inflation, taylor principle, and indeterminacy,* Journal of Money, Credit and Banking, v. 41, 8, pp. 1557-1584, **TD No. 708 (May 2007).**

S. COLAROSSI and A. ZAGHINI, *Gradualism, transparency and the improved operational framework: a look at overnight volatility transmission*, International Finance, v. 12, 2, pp. 151-170, **TD No. 710 (May 2009).**

M. BUGAMELLI, F. SCHIVARDI and R. ZIZZA, *The euro and firm restructuring*, in A. Alesina e F. Giavazzi (eds): Europe and the Euro, Chicago, University of Chicago Press, **TD No. 716 (June 2009).**

B. HALL, F. LOTTI and J. MAIRESSE, *Innovation and productivity in SMEs: empirical evidence for Italy*, Small Business Economics, v. 33, 1, pp. 13-33, **TD No. 718 (June 2009).**

2010

A. PRATI and M. SBRACIA, *Uncertainty and currency crises: evidence from survey data*, Journal of Monetary Economics, v, 57, 6, pp. 668-681, **TD No. 446 (July 2002).**

S. MAGRI, *Debt maturity choice of nonpublic Italian firms* , Journal of Money, Credit, and Banking, v.42, 2-3, pp. 443-463, **TD No. 574 (January 2006).**

R. BRONZINI and P. PISELLI, *Determinants of long-run regional productivity with geographical spillovers: the role of R&D, human capital and public infrastructure,* Regional Science and Urban Economics, v. 39, 2, pp.187-199, **TD No. 597 (September 2006).**

E. IOSSA and G. PALUMBO, *Over-optimism and lender liability in the consumer credit market*, Oxford Economic Papers, v. 62, 2, pp. 374-394, **TD No. 598 (September 2006).**

S. NERI and A. NOBILI, *The transmission of US monetary policy to the euro area,* International Finance, v. 13, 1, pp. 55-78, **TD No. 606 (December 2006).**

F. ALTISSIMO, R. CRISTADORO, M. FORNI, M. LIPPI and G. VERONESE, *New Eurocoin: Tracking Economic Growth in Real Time,* Review of Economics and Statistics, v. 92, 4, pp. 1024-1034, **TD No. 631 (June 2007).**

A. CIARLONE, P. PISELLI and G. TREBESCHI, *Emerging Markets' Spreads and Global Financial Conditions*, Journal of International Financial Markets, Institutions & Money, v. 19, 2, pp. 222-239, **TD No. 637 (June 2007).**

U. ALBERTAZZI and L. GAMBACORTA, *Bank profitability and taxation*, Journal of Banking and Finance, v. 34, 11, pp. 2801-2810, **TD No. 649 (November 2007).**

M. IACOVIELLO and S. NERI, *Housing market spillovers: evidence from an estimated DSGE model,* American Economic Journal: Macroeconomics, v. 2, 2, pp. 125-164, **TD No. 659 (January 2008).**

F. BALASSONE, F. MAURA and S. ZOTTERI, *Cyclical asymmetry in fiscal variables in the EU*, Empirica, **TD No. 671**, v. 37, 4, pp. 381-402 **(June 2008).**

F. D'AMURI, O. GIANMARCO I.P. and P. GIOVANNI, *The labor market impact of immigration on the western german labor market in the 1990s,* European Economic Review, v. 54, 4, pp. 550-570, **TD No. 687 (August 2008).**

A. ACCETTURO, *Agglomeration and growth: the effects of commuting costs,* Papers in Regional Science, v. 89, 1, pp. 173-190, **TD No. 688 (September 2008).**

S. NOBILI and G. PALAZZO, *Explaining and forecasting bond risk premiums*, Financial Analysts Journal, v. 66, 4, pp. 67-82, **TD No. 689 (September 2008).**

A. B. ATKINSON and A. BRANDOLINI, *On analysing the world distribution of income*, World Bank Economic Review , v. 24, 1 , pp. 1-37, **TD No. 701 (January 2009).**

R. CAPPARIELLO and R. ZIZZA, *Dropping the Books and Working Off the Books,* Labour, v. 24, 2, pp. 139-162 ,**TD No. 702 (January 2009).**

C. NICOLETTI and C. RONDINELLI, *The (mis)specification of discrete duration models with unobserved heterogeneity: a Monte Carlo study*, Journal of Econometrics, v. 159, 1, pp. 1-13, **TD No. 705 (March 2009).**

V. DI GIACINTO, G. MICUCCI and P. MONTANARO, *Dynamic macroeconomic effects of public capital: evidence from regional Italian data,* Giornale degli economisti e annali di economia, v. 69, 1, pp. 29-66, **TD No. 733 (November 2009).**

F. COLUMBA, L. GAMBACORTA and P. E. MISTRULLI, *Mutual Guarantee institutions and small business finance,* Journal of Financial Stability, v. 6, 1, pp. 45-54, **TD No. 735 (November 2009).**

A. GERALI, S. NERI, L. SESSA and F. M. SIGNORETTI, *Credit and banking in a DSGE model of the Euro Area*, Journal of Money, Credit and Banking, v. 42, 6, pp. 107-141, **TD No. 740 (January 2010).**

M. AFFINITO and E. TAGLIAFERRI, *Why do (or did?) banks securitize their loans? Evidence from Italy*, Journal of Financial Stability, v. 6, 4, pp. 189-202, **TD No. 741 (January 2010).**

S. FEDERICO, *Outsourcing versus integration at home or abroad and firm heterogeneity*, Empirica, v. 37, 1, pp. 47-63, **TD No. 742 (February 2010).**

V. DI GIACINTO, *On vector autoregressive modeling in space and time,* Journal of Geographical Systems, v. 12, 2, pp. 125-154, **TD No. 746 (February 2010).**

S. MOCETTI and C. PORELLO, *How does immigration affect native internal mobility? new evidence from Italy*, Regional Science and Urban Economics, v. 40, 6, pp. 427-439, **TD No. 748 (March 2010).**

A. DI CESARE and G. GUAZZAROTTI, *An analysis of the determinants of credit default swap spread changes before and during the subprime financial turmoil,* Journal of Current Issues in Finance, Business and Economics, v. 3, 4, pp., **TD No. 749 (March 2010).**

A. BRANDOLINI, S. MAGRI and T. M SMEEDING, *Asset-based measurement of poverty*, Journal of Policy Analysis and Management, v. 29, 2 , pp. 267-284, **TD No. 755 (March 2010).**

G. CAPPELLETTI, *A Note on rationalizability and restrictions on beliefs*, The B.E. Journal of Theoretical Economics, v. 10, 1, pp. 1-11,**TD No. 757 (April 2010).**

S. DI ADDARIO and D. VURI, *Entrepreneurship and market size. the case of young college graduates in Italy*, Labour Economics, v. 17, 5, pp. 848-858, **TD No. 775 (September 2010).**

FORTHCOMING

L. MONTEFORTE and S. SIVIERO, *The Economic Consequences of Euro Area Modelling Shortcuts*, Applied Economics, **TD No. 458 (December 2002).**

M. BUGAMELLI and A. ROSOLIA, *Produttività e concorrenza estera*, Rivista di politica economica, **TD No. 578 (February 2006).**

G. DE BLASIO and G. NUZZO, *Historical traditions of civicness and local economic development,* Journal of Regional Science, **TD No. 591 (May 2006).**

S. DI ADDARIO, *Job search in thick markets*, Journal of Urban Economics, **TD No. 605 (December 2006).**

F. SCHIVARDI and E. VIVIANO, *Entry barriers in retail trade*, Economic Journal, **TD No. 616 (February 2007).**

G. FERRERO, A. NOBILI and P. PASSIGLIA, *Assessing excess liquidity in the Euro Area: the role of sectoral distribution of money,* Applied Economics, **TD No. 627 (April 2007).**

P. E. MISTRULLI, *Assessing financial contagion in the interbank market: maximun entropy versus observed interbank lending patterns,* Journal of Banking & Finance, **TD No. 641 (September 2007).**

Y. ALTUNBAS, L. GAMBACORTA and D. MARQUÉS, *Securitisation and the bank lending channel*, European Economic Review, **TD No. 653 (November 2007).**

E. CIAPANNA, *Directed matching with endogenous markov probability: clients or competitors?*, The RAND Journal of Economics, **TD No. 665 (April 2008).**

M. BUGAMELLI and F. PATERNÒ, *Output growth volatility and remittances*, Economica, **TD No. 673 (June 2008).**

V. DI GIACINTO e M. PAGNINI, *Local and global agglomeration patterns: two econometrics-based indicators*, Regional Science and Urban Economics, **TD No. 674 (June 2008).**

G. BARONE and F. CINGANO, *Service regulation and growth: evidence from OECD countries,* Economic Journal, **TD No. 675 (June 2008).**

S. MOCETTI, *Educational choices and the selection process before and after compulsory school*, Education Economics, **TD No. 691 (September 2008).**

P. SESTITO and E. VIVIANO, *Reservation wages: explaining some puzzling regional patterns*, Labour, **TD No. 696 (December 2008).**

P. PINOTTI, M. BIANCHI and P. BUONANNO, *Do immigrants cause crime?*, Journal of the European Economic Association, **TD No. 698 (December 2008).**

R. GIORDANO and P. TOMMASINO, *What determines debt intolerance? The role of political and monetary institutions*, Journal of Political Economy, **TD No. 700 (January 2009).**

L. FORNI, A. GERALI and M. PISANI, *Macroeconomic effects of greater competition in the service sector: the case of Italy,* Macroeconomic Dynamics, **TD No. 706 (March 2009).**

Y. ALTUNBAS, L. GAMBACORTA, and D. MARQUÉS-IBÁÑEZ, *Bank risk and monetary policy,* Journal of Financial Stability, **TD No. 712 (May 2009).**

P. ANGELINI, A. NOBILI e C. PICILLO, *The interbank market after August 2007: What has changed, and why?*, Journal of Money, Credit and Banking, **TD No. 731 (ottobre 2009).**

L. FORNI, A. GERALI and M. PISANI, *The macroeconomics of fiscal consolidations in euro area countries,* Journal of Economic Dynamics and Control, **TD No. 747 (March 2010).**

A. DI CESARE and G. GUAZZAROTTI, *An analysis of the determinants of credit default swap spread changes before and during the subprime financial turmoil,* in C. V. Karsone (eds.), Finance and Banking Developments, Nova Publishers, New York., **TD No. 749 (March 2010).**

G. GRANDE and I. VISCO, *A public guarantee of a minimum return to defined contribution pension scheme members,* Journal of Risk, **TD No. 762 (June 2010).**

P. DEL GIOVANE, G. ERAMO and A. NOBILI, *Disentangling demand and supply in credit developments: a survey-based analysis for Italy,* Journal of Banking and Finance, **TD No. 764 (June 2010).**

G. BARONE and S. MOCETTI, *With a little help from abroad: the effect of low-skilled immigration on the female labour supply,* Labour Economics, **TD No. 766 (July 2010).**

S. MAGRI and R. PICO, *The rise of risk-based pricing of mortgage interest rates in Italy*, Journal of Banking and Finance, **TD No. 778 (October 2010).**