

# Optimal monetary policy in the euro area: the role of imperfect information and real time data\*

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## Abstract

This paper studies the implications of imperfect information and data revisions for the analysis of monetary policy using a small-scale DSGE model of the euro area and real-time data for the output gap and real GDP growth. The implications for monetary policy are analysed in terms of inflation-output gap volatility frontiers, the response of the central bank to shocks and the prescriptions for the nominal interest rate based on the Taylor rule and the optimal policy under discretion.

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# 1 Introduction

[...] *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's 53rd Annual Economic Conference, Chatham, Massachusetts June 9, 2008.

Theoretical research in the field of monetary economics has long sought to build macroeconomic models to rationalise the channels through which monetary policy decisions transmit to the economy. Over the last decades, the class of new Keynesian dynamic stochastic general equilibrium models (henceforth, NK-DSGE models) has witnessed an impressive deployment with innumerable applications both in theoretical and empirical works. NK-DSGE models, which combine a rigorous microeconomic derivation of the behavioural equations with a reasonable empirical fit of key macroeconomic time series, have brought new insights on various aspects of monetary policy-making.

One distinct feature of most NK-DSGE models is the assumption that agents and the central bank have perfect information about the state of the economy, i.e. that they can observe with exactness all the relevant economic variables and thus identify what type of shock has hit the economy. For example, under perfect information the central bank knows whether an observed rise in inflation is due to an adverse cost-push shock or to a positive demand shock and thus can react in the appropriate way. By contrast, in reality the “art of monetary policy-making” is inevitably conducted in an environment of pervasive uncertainty. Orphanides (2003) underlines the importance of recognising “...*the complications resulting from the presence of noise for the study of monetary policy...*”. In the case of inflation targeting over a medium-term horizon, in order to set the interest rate the central bank needs to forecast future inflation conditional on alternative scenarios.

Therefore, the central bank must use appropriately all the available information to obtain the best possible estimate of the current state of the economy and its future development.

From an empirical point of view, it is common practice to estimate NK-DSGE models using ex post revised data. The implications of real time estimates of commonly used macroeconomic time series for the estimation of such models have not received adequate attention. With respect to policy prescriptions based on Taylor rules Orphanides (2001) finds that “...*real-time policy recommendations differ considerably from those obtained with ex post revised data...*”.

In this paper we address the issue of imperfect information and data revisions for the analysis of monetary policy in the euro area using a small-scale NK-DSGE model. Our work is closely linked to a recent article by Lippi and Neri (2007) who base their analysis on the model developed in Ehrmann and Smets (2003). We extend the analysis along two important directions. First, we employ a different set of indicator variables that includes the euro-coin coincident indicator of the euro area business cycle, the Purchasing Managers’ Index and survey-based measures of inflation expectations. Second, we estimate the model using real time estimates of real GDP and the output gap and compare the monetary policy prescriptions with those obtained using ex post revised data.

An alternative approach to incorporate indicator variables has been used by Boivin and Giannoni (2006). Building on the factor model literature, the authors propose an empirical framework for the estimation of DSGE models that exploits the information contained in a large cross-section of data. Their methodology allows to obtain a better identification of the state variables that drive the model. However, the information contained in the data does not affect the behaviour of agents in the model since they observe with infinite precision the state variables that describe the dynamics of the economy. The assumption of imperfect information that characterises our approach may affect the transmission mechanism of shocks and increase the persistence of the dynamics of the model. Indeed, the response of agents to shocks may, in principle, be more muted if they are not able to identify the shocks that are hitting the economy.

The rest of the paper is organised as follows. Section 2 briefly presents the model,

describes how monetary policy is conducted and illustrates the signal extraction problem faced by agents. Section 3 presents the data and the estimation results. Section 4 analyses implications of imperfect information and data revisions for monetary policy in the euro area. Section 5 concludes.

## 2 A small-scale new Keynesian model

The model is taken from Ehrmann and Smets (2003) and is similar to Benati (2008). It is a small-scale reduced form NK-DSGE model which represents an economy populated by three types of agents: households, firms and the central bank. The model consists of the following structural equations:

$$y_t = \delta y_{t-1} + (1 - \delta) y_{t+1|t} - \theta (R_t - \pi_{t+1|t}) + u_{d,t} \quad (1)$$

$$\pi_t = \alpha \pi_{t-1} + (1 - \alpha) \pi_{t+1|t} + \kappa (y_t - \bar{y}_t) + u_{c,t} \quad (2)$$

$$\bar{y}_t = \rho \bar{y}_{t-1} + u_{\bar{y},t} \quad (3)$$

$$x_t = y_t - \bar{y}_t \quad (4)$$

where  $y_t$  is output,  $\pi_t$  inflation,  $R_t$  the short-term nominal interest rate,  $\bar{y}_t$  potential output, which is modeled as a first-order autoregressive process, and  $x_t$  the output gap. Subscript  $_{t+1|t}$  denotes the expected value of a variable in period  $t+1$  conditioned on information as of time  $t$ . There are three structural orthogonal innovations in the model with covariance matrix  $\Sigma_u^2$ : a demand shock  $u_{d,t}$ , a cost-push shock  $u_{c,t}$  and a shock to potential output  $u_{\bar{y},t}$ . This specification encompasses purely forward looking models (Rotemberg and Woodford, 1997, Clarida, Galí and Gertler, 1999 and Aoki, 2003), and backward looking models as the one described in Rudebusch (2002) and Orphanides (2003). Unlike Ehrmann and Smets (2003), we consider two different monetary regimes to close the model. This is what we turn to in the next section.

## 2.1 Monetary policy

We assume that the central bank sets the short-term nominal interest rate and may operate under two alternative monetary regimes: a discretionary monetary policy or a simple interest rate rule.

### 2.1.1 Monetary policy under the Taylor rule

Simple interest rate rules based on few targeted variables have performed reasonably well in explaining interest rate setting by central banks (see among other many other references, Orphanides, 2005).<sup>1</sup> Moreover, these rules represent good approximations to more complex optimal monetary policies and are fairly robust across different models (see for example Taylor, 1993).

In our model the central bank sets the nominal interest rate according to the following forward-looking rule:

$$R_t = \phi_R R_{t-1} + (1 - \phi_R) \left[ \phi_\pi \pi_{t+1,t|t-3}^{(4)} + \phi_x (y_{t|t} - \bar{y}_t) \right] \quad (5)$$

where the positive coefficients  $\phi_R$ ,  $\phi_\pi$  and  $\phi_x$  are such to ensure equilibrium determinacy.<sup>2</sup>

We chose a relative short horizon (one quarter) for the inflation rate on the basis of the results in Smets (2003). In this paper the author finds that the appropriate horizon for achieving price stability is shorter the greater is the weight attached to price stability in the society welfare function, the more forward-looking are inflation and output and the larger is the slope of the NKPC. The policy rate responds to contemporaneous annual inflation, output and the previous period policy rate. In particular, this latter term is meant to capture the inertia observed in policy interest rates.

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<sup>1</sup> In 2003 the Norges Bank hosted the workshop “The Role of Monetary Policy Rules in Inflation Targeting Regimes - Theory Meets Practice”.

<sup>2</sup> In other words, we make sure the postulated Taylor rule (5) does not lead to multiple equilibria or to instability. For further details see Blanchard and Kahn (1980).

### 2.1.2 Monetary policy under discretion

Under discretion the central bank expects itself to optimize at each successive date a welfare loss defined as the expected discounted sum of periods loss functions  $W_t$ :

$$L = E_0 \sum_{t=0}^{\infty} \beta^t W_t \quad (6)$$

where the period loss function is the weighted sum of the squared annual inflation rate  $\pi_{t,t-4} \equiv p_t - p_{t-4}$ , output gap  $y_t - \bar{y}_t$ , and the changes in the nominal short-term interest rate  $R_t - R_{t-1}$ :

$$W_t = \frac{1}{2} \left\{ \pi_{t,t-4}^2 + \nu_x (y_t - \bar{y}_t)^2 + \nu_R (R_t - R_{t-1})^2 \right\}. \quad (7)$$

The (non negative) parameters  $\nu_x$  and  $\nu_R$  measures how much weight is attributed to the stabilisation of output and the nominal interest rate relative to inflation, while  $\beta$  is the discount factor. As long as  $\nu_x$  and/or  $\nu_R$  are different from zero then the central bank is said to be a flexible inflation targeter (Svensson, 1999). In principle, these coefficients could be chosen so that the postulated loss function represented a second-order approximation of the representative household's utility function. However, in the present analysis, we prefer not to impose such restrictions on the preference parameters  $\nu_x$  and  $\nu_R$ . This specification of the loss function has been used by Adolfson, Laséen, Lindé and Svensson (2008) who show how to construct interest rate projections under the optimal policy in the DSGE model of the Sveriges Riksbank.

## 2.2 Imperfect information and signal extraction

In this Section we introduce imperfect information in the model and illustrate how this assumption affects the central bank's behaviour and the dynamics of the system.

In a situation of (symmetric) imperfect information the private sector and the central bank cannot directly observe the state of the economy. Some state variables may only be measured with errors and/or with lags. As an example, one may think of data for real Gross Domestic Product (GDP) which are available only with a substantial delay and that

are often subject to later revisions. Coenen, Levin and Wieland (2005) study the revisions for a set of macroeconomic variables for the euro and find that some of them, in particular, output, have been subject to significant revisions even after nearly a year from the first release of the new data. Other state variables, such as structural shocks, are simply unobservable. This makes the task of making decisions under imperfect information more complex than under complete information. Broadly speaking, the difference is due to the fact that agents in the model need to estimate the current state of the economy and its future development distilling information from the set of noisy indicators at their disposal. Thus, agents face a signal extraction problem and must weigh all available information to draw the most efficient inference. Filtering leads to hump-shaped responses as both private agents and the central bank respond “cautiously” to shocks and then adjust more rapidly as they better identify the state of the economy (see Collard and Dellas, 2006).

Let us now define the law of motion of the linearized model economy as:

$$\begin{bmatrix} X_{t+1} \\ x_{t+1|t} \end{bmatrix} = \mathbf{A} \begin{bmatrix} X_t \\ x_t \end{bmatrix} + \mathbf{B}R_t + \begin{bmatrix} u_{t+1} \\ 0 \end{bmatrix} \quad (8)$$

where  $X_t$  is a  $n_X$ -vector of all state variables (both endogenous and exogenous),  $x_t$  is a  $n_x$ -vector of forward-looking variables and  $R_t$  is the monetary policy rate. Finally,  $u_t$  is a  $n_u$ -vector of innovations to the model structural shocks.<sup>3</sup> Finally,  $\mathbf{A}$  and  $\mathbf{B}$  are matrices of appropriate dimension.

Svensson and Woodford (2003) show that in a linear-quadratic model with a partially observable state of the economy, the optimal nominal interest rate that arises under discretion is a linear function of the current estimate of the states vector, i.e.,  $X_{t|t}$ , rather than of its actual value, i.e.,  $X_t$ :

$$R_t = \mathbf{F}^d X_{t|t} \quad (9)$$

where the matrix  $\mathbf{F}^d$  contains the optimal feedback coefficients. Notice that the closed-form solution (9) fulfils the so called separation principle. With a partially observable

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<sup>3</sup> The matrix  $\mathbf{A}_2$  that shows up in the representation of Svensson and Woodford (2003) is nil.

state of the economy, the central bank can treat as two separate tasks the optimization problem, which concerns the finding of matrix  $\mathbf{F}^d$ , and the filtering problem, which has to do with the computation of the vector  $X_{t|t}$ . As regards the former problem, the optimal feedback coefficients can be computed as if the vector  $X_t$  were perfectly observable, using one of the various numerical toolkit that solve linear-quadratic optimal problem under perfect information.<sup>4</sup> As regards the filtering problem we briefly describe how agents in the model may use the Kalman filter to compute  $X_{t|t}$ .

To cast the Taylor rule in the system (7) it is sufficient to provide an expression analogous to (9) but where the matrix that pre-multiply  $X_{t|t}$  (and possibly  $x_{t|t}$ ) is structured as to replicate the postulated monetary policy rule (5):

$$R_t = \begin{bmatrix} \mathbf{F}_1^{tr} & \mathbf{F}_2^{tr} \end{bmatrix} \begin{bmatrix} X_{t|t} \\ x_{t|t} \end{bmatrix}. \quad (10)$$

We assume that in period  $t$  agents have access to a number of observable indicators which are stacked in the  $n_Z$ -vector named  $Z_t$ . Observable indicators represent noisy measures of the true endogenous variables in the economy, through the linear mapping:

$$Z_t = \begin{bmatrix} \mathbf{D}_1 & \mathbf{D}_2 \end{bmatrix} \begin{bmatrix} X_t \\ x_t \end{bmatrix} + v_t, \quad (11)$$

where  $\mathbf{D}_1$  and  $\mathbf{D}_2$  are matrices of appropriate dimension and the  $n_Z$ -vector  $v_t$  contains the measurement errors which are assumed to be independent from  $u_t$  at all leads and lags. Using the result  $x_{t|t} = \mathbf{G}X_{t|t}$  (see Svensson and Woodford (2003) for a derivation), the dynamics for  $X_t$ ,  $Z_t$  and  $x_t$  obey the equations:

$$X_{t+1} = \mathbf{H}X_t + \mathbf{J}X_{t|t} + \mathbf{C}u_{t+1}, \quad (12)$$

$$Z_t = \mathbf{L}X_t + \mathbf{M}X_{t|t} + \nu_t, \quad (13)$$

$$x_t = \mathbf{G}X_{t|t} + \mathbf{G}^1(X_t - X_{t|t}). \quad (14)$$

It is left to specify the optimal filter of  $X_{t|t}$ . Notice first that, by looking at (12) and

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<sup>4</sup> See Soderlind (1999) and Gerali and Lippi (2003).

(13), the estimation of the predetermined vector  $X_t$  has been transformed to a problem without forward-looking variables  $x_t$ . This means that one can easily apply the standard Kalman Filter. Thus, to carry out the efficient estimate of the contemporaneous state vector  $X_{t|t}$ , agents update the previous period forecast by applying the Kalman Filter to the most recent information embedded in  $Z_t$ . The law of motion of the optimal prediction  $X_{t|t}$  fulfills:

$$X_{t|t} = X_{t|t-1} + \mathbf{K} (Z_t - Z_{t|t-1}) \quad (15)$$

where  $\mathbf{K}$  is the (steady state) Kalman gain matrix:

$$\mathbf{K} \equiv \mathbf{P}\mathbf{L}' (\mathbf{L}\mathbf{P}\mathbf{L}' + \Sigma_{vv})^{-1} \quad (16)$$

which depends, among other things, on the covariance matrix of the innovations  $u_t$   $\Sigma_u^2$  and the measurement errors  $\Sigma_u^2$ . The Kalman gain matrix determines the optimal weights to be attached to the forecast errors in the observable indicators, i.e.,  $Z_t - Z_{t|t-1}$ , when updating the current estimate  $X_{t|t}$ . In case these innovations display fairly large variances, i.e., their informative power is scant, then the weights placed on them will be limited. Conversely, greater importance will be given to those innovations that present smaller variances. Because of this signal extraction problem, imperfect information represents, together with the various nominal and real rigidities, a source of persistence in macroeconomic variables. Even in a fully forward-looking model, in which the adjustment path after a shock would be immediate under perfect information, agents behave prudently and respond with gradualism because they are unable to discern exactly the type of shock that is hitting the economy.

The effect of imperfect information on monetary policy can be gauged by combining equations (9) and (15):

$$R_t = \mathbf{F}^d X_{t|t} = \mathbf{F}^d [X_{t|t-1} + \mathbf{K} (Z_t - Z_{t|t-1})]. \quad (17)$$

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.

As the estimate of the current state of the economy is a distributed lag of observable variables, the central bank learns the value of  $X_{t|t}$  only slowly. In other words, the optimal policy rate will exhibit a certain degree of gradualism or caution in response to movements in macroeconomic variables (see Aoki, 2003).

### 3 Empirical analysis

In this Section we discuss the estimation and present the results by comparing the posterior distribution of the parameters across models. We then focus on the transmission of shocks and the differences in the behaviour of monetary policy across models.

In order to estimate the model, we first construct its state-space representation:

$$Q_{t+1} = \tilde{\mathbf{A}}Q_t + \tilde{\mathbf{B}}\epsilon_{t+1} \quad (18)$$

where  $Q_t$  is a vector that includes the true state variables  $X_t$  and the agents' estimates  $X_{t|t-1}$ , while  $\epsilon_{t+1}$  consists of shocks  $u_{t+1}$  and the measurement errors of the indicator variables  $v_t$ . Equation (18) allows to express the vector of observable variables and the short-run nominal interest rate:

$$d_t = \begin{bmatrix} Z_t \\ R_t \end{bmatrix} = \tilde{\mathbf{L}}Q_t + \tilde{\mathbf{M}}v_t \quad (19)$$

The conformable matrices  $\mathbf{A}, \mathbf{B}, \mathbf{L}$  and  $\mathbf{M}$  are defined in Lippi and Neri (2007). The assumption of imperfect information complicates the evaluation of the likelihood of the model since it modifies the Kalman filtering that must be used to compute the prediction errors of the observables. In particular, the assumption that the measurement errors  $v_t$  attached to the indicator variables in the model are the same that the econometrician attaches to the the observables  $d_t$  creates an additional link between the measurement equation (19) and the state space representation (18). In particular, the correlation between  $\epsilon_{t+1}$  and  $v_t$  modifies the Kalman gain matrix  $K_t$  which measures the information content of each indicator for forecasting the state vector:

$$K_t \equiv \left( \mathbf{A}\Sigma_{t|t-1}^2 \mathbf{L}' + \mathbf{B}V_3 \right) \left( \mathbf{L}\Sigma_{t|t-1}^2 \mathbf{L}' + V_2 \right)^{-1} \quad (20)$$

where  $\Sigma_{t|t-1}^2$  is the covariance matrix of the forecast errors of  $Q_t$  and the matrix  $V_3$  is different from zero under the assumptions of imperfect information and that the econometrician attaches the measurement errors  $v_t$  to the data (see Lippi and Neri, 2005 for a derivation of the matrix  $V_3$ ). The Kalman gain becomes:

$$K_t \equiv \mathbf{A}\Sigma_{t|t-1}^2\mathbf{L}' \left( \mathbf{L}\Sigma_{t|t-1}^2\mathbf{L}' + V_2 \right)^{-1} \quad (21)$$

if agents have perfect information on the shocks in the model and, hence, there are no measurement errors attached to the observables. In this case  $X_t = X_{t|t-1}$  and  $Q_t$  becomes simply  $X_t$ .<sup>5</sup>

A final remark on the estimation of the standard deviation of the noise is necessary. We decided to estimate both the noise and the structural parameters. Indeed, the importance of this joint estimation has been studied in Lippi and Neri (2007) who found that in terms of the fit maximum likelihood (ML) performs much better than the two-stage method, adopted for example in Ehrmann and Smets (2003).

### 3.1 Data and prior distribution

We use quarterly data for the euro area for the period 1999:1-2008:3. We chose to start at the beginning of the European Monetary Union when the ECB took the responsibility for the single monetary policy. In addition, this sample is characterized by very low persistence in inflation as the nominal convergence within the participating members of the EMU had already taken place. Benati (2008) finds a substantial fall in inflation persistence following the introduction of the EMU.

Data on the interest rate  $R$  refer to the fixed/minimum bid rate (henceforth, MBR) on the main refinancing operations. We opted for this rate instead of a short-term nominal interest rate, such as the 3-month Euribor rate, in order to avoid possible estimation biases due to the money market turmoil that started in the summer of 2007.<sup>6</sup> Inflation is

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<sup>5</sup> The presence of  $V_3$  also modifies the update of the covariance matrix of the forecast errors of the state variables  $\Sigma_{t+1|t}^2$ .

<sup>6</sup> From August to December of 2007, the average spread between the 3-month Euribor rate and the MBR was about 65 basis points. It increased substantially after mid-September 2008.

measured by the year-on-year changes in the Harmonised Consumer Price Index (HICP) while inflation expectations one quarter ahead are taken from Consensus Economics. The output gap, both in real time and ex post terms, is taken from the OECD (Economic Outlook) and IMF (World Economic Outlook) while real time GDP is taken from the Euro Area Business Cycle Network and updated using the Monthly Bulletin of the ECB. The revised version is taken from Eurostat. The Purchasing Managers' Index for the manufacturing sector is taken from Reuters and the €-coin indicator from the Banca d'Italia. The time series used in the estimation are reported in Figure 1. We adopted the following transformations of the data: current inflation, inflation expectations, the nominal interest rate, the output gap and €-coin are all demeaned. Real GDP is linearly detrended assuming a steady state quarterly growth rate equal to the sample mean (0.45 per cent). Finally, the PM index is log transformed and de-meaned.

Table 1 presents the summary statistics for the prior distribution. The mean of the prior distribution for the weight on the lag of inflation in the NK Phillips curve is set to 0.5 following the calibration in Orphanides (2003) and Orphanides and Williams (2007). The mean of the prior on the coefficient on the lag of output in the aggregate demand curve is set to 0.5 following Orphanides and Williams (2007). These mean values are close to estimates in Ehrmann and Smets (2003) while, as far as the coefficient on the lag of output is concerned, it differs from the value found by Lippi and Neri (2007) using Maximum Likelihood (0.79). The mean of the prior for  $\theta$ , the elasticity of aggregate demand to the real interest rate, and  $\kappa$  are set to, respectively, 0.25 and 0.1. These values are close to the estimates in Orphanides (2003). Benati (2008) sets a prior mean for  $\kappa$  of 0.05 and for  $\theta$  of 0.5. His posterior distributions (see Table XII) seem to 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 of the response of the policy rate to inflation is set to 0.5 which, taking into account that the monetary authority aims at stabilising the yearly changes in the price index and that we measure the interest rate in quarterly (not annualised) terms, corresponds to a value of 2.0, larger than the conventional 1.5. The mean prior response to the output

gap and the coefficient measuring the inertia in interest rate setting are also equal to 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 at 0.01. We calibrate only the discount factor  $\beta$  in the intertemporal loss function (4) and set it to 0.995 which corresponds to a steady state real interest rate of 2.0 per cent on annual basis. Draws from the posterior distribution of the parameters are obtained using the Metropolis algorithm.

### 3.2 Posterior distribution

Table 2 reports the median and 0.95 probability intervals for the structural parameters based on 200,000 draws from the posterior. The statistics for the posterior are reported for the three models we have estimated: the one with imperfect information and real time data, the one with perfect information and real time data and, finally, the one with perfect information and ex post data.

The posterior distribution suggests that both forward and backward components are important for output and inflation dynamics. This finding is consistent with previous studies, e.g. Galí and Gertler (1999) and Lippi and Neri (2007). Interestingly we find a significant weight on the lag of inflation in all the three models (around 0.20 on average). On the basis of a similar models, Benati (2008) finds that inflation persistence arising from indexation of prices becomes null over the EMU sample.

The median of the interest rate elasticity of the demand curve is in line with the estimates in Lippi and Neri (2007) and the marginal posterior distributions are similar across models. Larger differences emerge for the slope of the NKPC. In particular, the model with perfect information estimated with ex post data suggest a very low sensitivity of inflation to the output gap (0.004). In this model, the median is very close to the maximum likelihood estimate in Lippi and Neri (2007). The value of this parameter is crucial for the ability of monetary policy in stabilising inflation and for the trade off the central bank faces when the economy is hit by supply shocks. We return to this issue later.

With regards to the Taylor rule, inference on the posterior distribution indicates that there are differences in the marginal distribution of  $\phi_\pi$  primarily across data set. Indeed, when revised data are employed in the estimation, a larger response to inflation is found (the median is 0.43). On the contrary, when real time data are used the median of  $\phi_\pi$  falls to 0.31 regardless of the information set up. At the same time, the marginal posterior of  $\phi_x$  shows some differences across data set and also across information set up. In particular, the median obtained with ex post data is significantly smaller (0.17) than with real time data (0.29 and 0.22 with, respectively, imperfect and perfect information). Interestingly, Orphanides (2001) for the US and Gerdesmeier and Roffia (2005) for the euro area find a more muted response to inflation and a larger one to the output gap in a Taylor rule estimated with real time data. Finally, differences also emerge for the marginal posterior distribution of the interest rate smoothing coefficient  $\phi_R$  which in the case of revised data is shifted towards zero. Orphanides (2001) finds a larger degree of interest rate inertia when real time data for the US are employed.

### 3.3 Model dynamics: the role of information and indicators

In order to assess the dynamic properties of the estimated model we compute impulse responses to structural shocks. Our objective is twofold. Firstly, we want to highlight the effects due to agents' misperception. We shall see that assuming imperfect information drives a temporary wedge between the true state of the economy (which is not observable) and the perceived (or filtered) one. Secondly, we want to assess the role of the indicator variables in alleviating the misperception errors. In other words, we ask to what extent temporary wedges between actual and filtered variables differ when varying the information available to agents. Figures 4 to 6 report the actual and perceived responses to, respectively a cost-push shock, a shock to aggregate demand and a shock to potential output. For comparison purposes, we also report the impulse responses that we obtained in the model with perfect information.<sup>7</sup>

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<sup>7</sup> Impulse response functions are computed using the medians of the marginal posterior distribution of the parameters.

Let us start with a cost-push shock (Figure 4). If the central bank had perfect information on the shocks hitting the economy, she would respond to the increase in inflation by raising the nominal interest rate. The output gap would then decline following the increase in the real interest rate and inflation would slowly return to the steady state. In the more realistic case of imperfect information, the dynamic adjustment substantially changes. The very first issue agents have to solve when they perceive a change in  $\pi_{t|t}$  and  $x_t$  is to understand which shock or shocks is responsible for it. Looking at Figure 4 it is evident that agents are confused as regards the true shock that triggered the rise in inflation. Agents and the central bank estimate that a combination of the three shocks has actually hit the economy: a small but positive cost-push shock, a negative shock to potential output and a tiny but positive demand shock. Due to this misperception of the shocks output and inflation react by less and, consequently, the central bank raises the nominal interest rate by less. Misperceptions about the shocks persist for several periods. Only after more than one year the true cost-push shock is accurately identified. The underestimation of the actual cost-push shock opens up (for a given increase in the policy rate) an initial wedge between actual and filtered inflation that gradually disappears. As regards the output gap, on the contrary, agents seem to filter out its actual value with great precision.

Figure 5 shows the impulse responses to an aggregate demand shock. Under perfect information the central bank would react to the increase in aggregate demand by gradually raising the policy rate for several periods. Both output and inflation would slowly return to steady state. Under imperfect information, agents once again are subject to a great deal of misperception about the true nature of the shocks buffeting the economy; in particular, the demand shock is somewhat underestimated and agents perceive also a negative shock to potential output. As a result the central bank acts more cautiously and raises less the policy rate. However, the response of monetary policy is barely affected by the assumption on the information set of agents.

The responses to a potential output shock are shown in Figure 6. Under perfect information, the central bank would immediately cut the nominal interest rate to boost

aggregate demand and counteract the initial fall in inflation. As the nominal interest rate remains below steady state the output gap would continue to increase, causing inflation to pick up and forcing the central bank to raise the policy rate. Quite interestingly, in the case of imperfect information at the time the true shock hits the economy agents perceive very small negative cost-push and positive potential output shock. Accordingly, the central bank barely responds and so do perceived inflation and output. However, without the monetary stimulus the fall in inflation would be larger than under perfect information. In the following period, private agents and the central bank revise their estimates about the state of the economy and rightly perceive that a potential output shock might indeed be in place. The monetary authority cuts the nominal interest rate, perceive output increases and deflation decelerates. Interestingly, in response to a shock to potential output assuming imperfect information has a destabilising effect on inflation and the output gap. In other words, the monetary policy inaction in the period the actual shock hits the economy calls for future remedy.

Imperfect information represents a source of confusion for the private sector and the central bank alike. Imperfectly informed agents can make substantial mistakes when attempting to estimate the state of the economy. We study the role of indicator variables and their informative contribution to estimate more accurately the unobservable state of the economy. To this purpose, in Figures 7-9 we compare the impulse responses of the actual and filtered variables for two different (but nested) information sets. It is important to recall that in either cases agents observe the true states of the economy. In the “*more informed*” scenario agents have access to six indicator variables, i.e., annual inflation, lagged output gap, €-coin, PMI, lagged GDP, inflation expectations, whereas in the “*less informed*” scenario agents observe only annual inflation and the (lagged) output gap. Visual inspection reveals that having at disposal a relatively larger set of indicators variables helps agents estimating more accurately the state of the economy. Indeed, it is striking to see that in the less informed scenario the filtering problem of shocks is very poor. The wedges between the responses of the actual and the filtered variables become remarkably wider. The highly distorted estimation of the *exogenous* states of the economy

leads indeed agents and the central bank to respond more cautiously. For example, in the case of a positive aggregate demand shock, in the less informed case the central bank barely increases the nominal interest rate and as a result filtered output gap and inflation turn out to be less volatile.

## **4 Imperfect information and data revisions: Implications for monetary policy**

In this Section we assess the implications of imperfect information and data revisions for monetary policy in terms of policy prescriptions, output gap-inflation volatility frontiers and interest rate projections.

### **4.1 Monetary policy in the euro area: prescriptions from the Taylor rule and the optimal policy under discretion**

One dimension along which the estimated models are different is the policy rate predicted by the Taylor rule and, for given weights in the loss function (7), the optimal discretionary policy. In order to compare the models we fixed the parameters at the median of their marginal posterior distributions. Figure 10 shows the interest rates implied by the Taylor rules in the three models.<sup>8</sup>

As far as the Taylor rule is concerned, two periods can be identified. In the first one, around the peak of policy tightening in 2000, the minimum bid rate appears to be in line with the prescription of the rule in the models with perfect information. On the other hand, according to the model with imperfect information, the interest rate was below the level reached by the official rate both at peak of the tightening cycle (4.75) and during the whole year 2000.

In the second period, from mid 2007 to 2008:3, the rule in the model with imperfect information indicates a policy rate slightly higher (50 basis points) than the level actually

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<sup>8</sup> It must be borne in mind that the analysis based on the estimated Taylor rule does not have normative implications. Nonetheless, we think it is useful in its own to identify periods in which the ECB deviated from the estimated rule that characterizes its behaviour over time.

reaches in the summer of 2008. According to the other two models the minimum bid rate was in line with the past behaviour of the ECB in our sample summarised by Taylor rule.

The bottom panel of Figure 10 reports the nominal interest rate predicted by the optimal policy under discretion. Using the state variables ( $X_{t|t}^{tr}$ ) estimated by the models with the Taylor rule characterizing monetary policy we construct the interest rate that would have been chosen optimally by a discretionary policy-maker in each quarter of our sample:

$$R_t = \mathbf{F}^d X_{t|t}^{tr}. \quad (22)$$

which can be computed invoking the separation principle between the problems of optimization of the policy and filtering. The matrix  $\mathbf{F}^d$  is evaluated at the median of the posterior distribution of the parameters and setting the preference parameters  $\nu_R$  and  $\nu_y$  at 2.0 and 0.25, respectively. The exercise aims simply at comparing how the optimal policy would have set interest rates had it faced the same macroeconomic environment ( $X_{t|t}^{tr}$ ) as the policy-maker that had followed the Taylor rule. In this sense, we do not take into account the effects on the economy induced by a different monetary policy.

Figure 11 plots the policy rate obtained by minimising the intertemporal loss function (7) assuming that the parameters of the different models are fixed at median values of the marginal posterior distributions. As for the Taylor rule, two periods can be identified. In the first one, around the peak of policy tightening in 2000, the minimum bid rate should have been raised more than the ECB actually did according to the model with perfect information estimated either with real time or revised data. On the contrary, the model with imperfect information and real time data would suggest a level of the policy rate at the peak of the tightening cycle not far from the 4.75 reached at the end of 2000. Similarly, in the recent phase of the monetary cycle, the optimal policy in the two models with perfect information would have called for a higher rate in 2007, at 4.75 per cent, and a lower one in mid-2008 (between 3.75 and 4.0 per cent). In an economy with imperfectly informed agents, the optimal policy would have kept raising the minimum bid rate during 2007 and 2008 up to 5.0 per cent in response to the high level of inflation and its expectations.

As a final remark, it is interesting to note that all the models suggest that the prolonged phase of monetary accommodation between 2003 and 2005 was in line with the prescriptions of the Taylor rule.

## 4.2 Monetary policy trade-offs

We now study the monetary policy trade-off between output and inflation stabilisation. To address this issue we analyse and compare the output-inflation variability frontiers arising in the alternative settings we discussed earlier. It is important to underline that in order to assess the policy trade-offs by means of output gap-inflation volatility frontiers it is crucial to jointly estimate the variances of the shocks and the measurement errors and the parameters of the model as the two sets of parameters jointly shape the frontiers. Indeed, Lippi and Neri (2007) show that neglecting the simultaneity problem that arises when a two-steps procedure that separately estimates the parameters of the model and the noise in the indicators can lead to significant underestimations of the magnitude of measurement errors and of the slope of the Phillips curve.

The policy frontier traces out the combinations of the unconditional variance of output gap and inflation that are feasible in terms of monetary policy. In practice, as we described monetary policy by a Taylor rule we chose to construct the frontier by varying the values of the coefficient  $\phi_x$  while keeping the remaining structural parameters at their posterior median values. To obtain a meaningful trade-off we shut down the demand shocks and keep active only the cost-push and potential output shocks. Indeed, these are the shocks induce movements of the output gap and inflation in opposite directions. In general, the policy frontier is expected to be convex towards the origin or at least negatively-sloped. Moving along the frontier from the north-west to the south/east shows the effects of increasing in  $\phi_x$ . As the central bank becomes relatively more aggressive towards the output gap it delivers a lower variance of this variable at the expense of higher inflation variability

Figure 12 displays a family of policy frontiers. The green policy frontier is drawn using the median of the marginal posterior distributions of the parameters of the model

with perfect information and revised data. The red policy frontier, instead, uses the model with perfect information and real time data. Finally, the blue frontier is drawn using the model with imperfect information and real time data. Visual inspection of the figure reveals several interesting results. Firstly, and more importantly, as one moves away from the model with perfect information and revised data towards more realistic settings characterized by real time data and/or imperfect information, the policy frontier substantially deteriorates. This can be spotted by the remarkable shift of the policy frontier to the north-east region of plane. In line with the findings in Orphanides (2003), the combinations of output gap and inflation variances obtainable with revised data and perfect information become simply infeasible in the other settings. Therefore, the policy-maker cannot deliver any of the outcome lying on the green line. Secondly, explicitly taking into account the noise in the data and its consequences on the behaviour of agents and the central bank makes the monetary policy trade-off even worse. The estimated policy frontier further shifts north-east and at the same time becomes flatter for high values of the volatility of inflation.

### 4.3 Policy projections

In this Section we use the model under the Taylor rule and the version solved under discretion to construct projections for the interest rate over the period 2008:4-2010:4 and to show how they can be sensitive to the assumptions on the information set and the data used in the estimation. In order to highlight the role of these two features, we assume a common scenario over which we project the different models. Moreover, in the case of the optimal discretionary policy we use the same values for the parameters in the loss function, namely 0.25 for  $\phi_x$  and 2 for  $\phi_R$ .

The scenario is obtained from several sources of information including Consensus Economics, the OECD, the IMF and private forecasters. In order to minimise the effects of the assumptions for the policy rate on the simulation we set its measurement error  $\sigma_R^v$  to 10 per cent. In this case path for the interest rate does not influence the computation of the policy rates consistent with the optimal policy rate and the Taylor rule. The evolution

of the economy and the policy interest rate are characterized by equations (18) and (19).

We use the model with the Taylor rule in order obtain estimates the unobserved states with the Kalman filter the period up to 2008:3 and then we switch to the optimal discretionary policy for the period 2008:4 - 2010:4. For comparison, we also simulate the interest rate under the Taylor rule over the projection horizon. Figure 13 reports the simulated paths for the policy rate under the Taylor rule (top panel) and the optimal monetary policy (bottom panel). Several things are worth noting. First, in the case of the optimal policy the model with imperfect information suggest that the interest rate should be lowered to 2.75 in mid 2009 while the model with perfect information would suggest a 75 basis points higher rate at that time. Under the Taylor rule the differences between the prescriptions of these two models are slightly smaller (50 basis points). Second, when the model with perfect information (either the one based on the Taylor or the optimal policy) is estimated over revised data both policies would call for a significantly lower interest rate, as low as 0.5 per cent under the optimal policy.

In all the simulations, a lower policy rate, compared to that prevailing in the third quarter of 2008, would be the result of a widening of the output gap and a moderation in inflation that would slowly converge to values in line with the definition of price stability. In terms of the driving forces, the scenario for growth and inflation would be the result of a negative demand and potential output shock and a positive cost-push shock that would dissipate rapidly over the projection horizon.

## 5 Concluding remarks

This paper studies the implications of imperfect information and data revisions for the analysis of monetary policy using a small-scale DSGE model for the euro area and real-time data for the output gap and real GDP growth. The implications for monetary policy are analysed in terms of inflation-output gap volatility frontiers, the response to the central bank to shocks and the optimal prescriptions for the interest rate.

# Tables and Figures

**Table 1.** Summary statistics for the prior distribution of the parameters

Parameter	Type	Range	Mean	St. Dev.	2.5	50	97.5
$\alpha$	Beta	[0,1)	0.5	0.1	0.3057	0.5003	0.6940
$\beta$	Beta	[0,1)	0.5	0.1	0.3057	0.5003	0.6940
$\theta$	Gamma	$\mathfrak{R}+$	0.25	0.1	0.0941	0.2368	0.4805
$\kappa$	Gamma	$\mathfrak{R}+$	0.1	0.05	0.0272	0.0918	0.2191
$\phi_\pi$	Gamma	$\mathfrak{R}+$	0.5	0.1	0.3237	0.4933	0.7139
$\phi_x$	Normal	$\mathfrak{R}$	0.5	0.1	0.3031	0.4999	0.6962
$\phi_R$	Beta	[0,1)	0.5	0.1	0.3053	0.4999	0.6939
$\rho_c$	Beta	[0,1)	0.7	0.1	0.4879	0.7070	0.8743
$\rho_d$	Beta	[0,1)	0.7	0.1	0.4879	0.7070	0.8743
$\rho_{\bar{y}}$	Beta	[0,1)	0.1	0.1	0.4879	0.7070	0.8743
$\sigma_c^u$	Gamma	$\mathfrak{R}+$	0.01	0.005	0.0027	0.0092	0.0219
$\sigma_d^u$	Gamma	$\mathfrak{R}+$	0.01	0.005	0.0027	0.0092	0.0219
$\sigma_{\bar{y}}^u$	Gamma	$\mathfrak{R}+$	0.01	0.005	0.0027	0.0092	0.0219
$\sigma_x^u$	Gamma	$\mathfrak{R}+$	0.01	0.005	0.0027	0.0092	0.0219
$\sigma_e^u$	Gamma	$\mathfrak{R}+$	0.01	0.005	0.0027	0.0092	0.0219
$\sigma_{pm}^u$	Gamma	$\mathfrak{R}+$	0.01	0.005	0.0027	0.0092	0.0219
$\sigma_y^u$	Gamma	$\mathfrak{R}+$	0.01	0.005	0.0027	0.0092	0.0219
$\sigma_{\pi^e}^u$	Gamma	$\mathfrak{R}+$	0.01	0.005	0.0027	0.0092	0.0219
$\sigma_\pi^u$	Gamma	$\mathfrak{R}+$	0.01	0.005	0.0027	0.0092	0.0219
$\sigma_R$	Gamma	$\mathfrak{R}+$	0.01	0.005	0.0027	0.0092	0.0219

**Table 2.** Summary statistics for the prior and posterior distribution of the parameters

parameter	II-RT			PI-RT			PI-EP		
	2.5	50	97.5	2.5	50	97.5	2.5	50	97.5
$\alpha$	0.1286	0.1956	0.2719	0.2226	0.2631	0.2973	0.2104	0.2321	0.2757
$\beta$	0.5173	0.6202	0.7411	0.4880	0.5874	0.7035	0.5825	0.6404	0.6903
$\theta$	0.2420	0.3232	0.4141	0.2350	0.3087	0.3962	0.2005	0.2812	0.3589
$\kappa$	0.0030	0.0113	0.0349	0.0065	0.0205	0.0591	0.0013	0.0039	0.0121
$\phi_\pi$	0.2545	0.3091	0.4187	0.2548	0.3130	0.4150	0.3448	0.4301	0.5349
$\phi_x$	0.1871	0.2943	0.3986	0.1801	0.2294	0.2823	0.1356	0.1717	0.2103
$\phi_R$	0.3884	0.4616	0.4982	0.4057	0.4582	0.4879	0.2104	0.2870	0.3606
$\rho_c$	0.4656	0.6108	0.7626	0.6253	0.6788	0.7343	0.5704	0.5993	0.6263
$\rho_d$	0.7009	0.7819	0.8592	0.7140	0.7717	0.8292	0.7340	0.8028	0.8574
$\rho_{\bar{y}}$	0.7969	0.8711	0.9179	0.7361	0.8354	0.9135	0.6454	0.7485	0.8482
$\sigma_c^u$	0.0001	0.0004	0.0008	0.0002	0.0004	0.0006	0.0002	0.0002	0.0004
$\sigma_d^u$	0.0004	0.0006	0.0010	0.0004	0.0006	0.0008	0.0004	0.0006	0.0009
$\sigma_{\bar{y}}^u$	0.0017	0.0025	0.0036	0.0020	0.0028	0.0037	0.0005	0.0012	0.0022
$\sigma_x^u$	0.0007	0.0043	0.0064	0.0005	0.0012	0.0024	0.0022	0.0030	0.0041
$\sigma_e^u$	0.0005	0.0007	0.0011	0.0004	0.0007	0.0010	0.0004	0.0006	0.0010
$\sigma_{pm}^u$	0.0002	0.0003	0.0003	0.0002	0.0002	0.0003	0.0002	0.0003	0.0004
$\sigma_y^u$	0.0010	0.0014	0.0019	0.0012	0.0015	0.0019	0.0016	0.0022	0.0029
$\sigma_{\pi^e}^u$	0.0017	0.0024	0.0034	0.0013	0.0021	0.0030	0.0022	0.0028	0.0037
$\sigma_\pi^u$	0.0023	0.0032	0.0048	0.0021	0.0029	0.0040	0.0033	0.0043	0.0058
$\sigma_R$	0.0001	0.0003	0.0015	0.0008	0.0011	0.0015	0.0001	0.0002	0.0006

*Note:* Results based on 200,000 draws from the Metropolis algorithm.

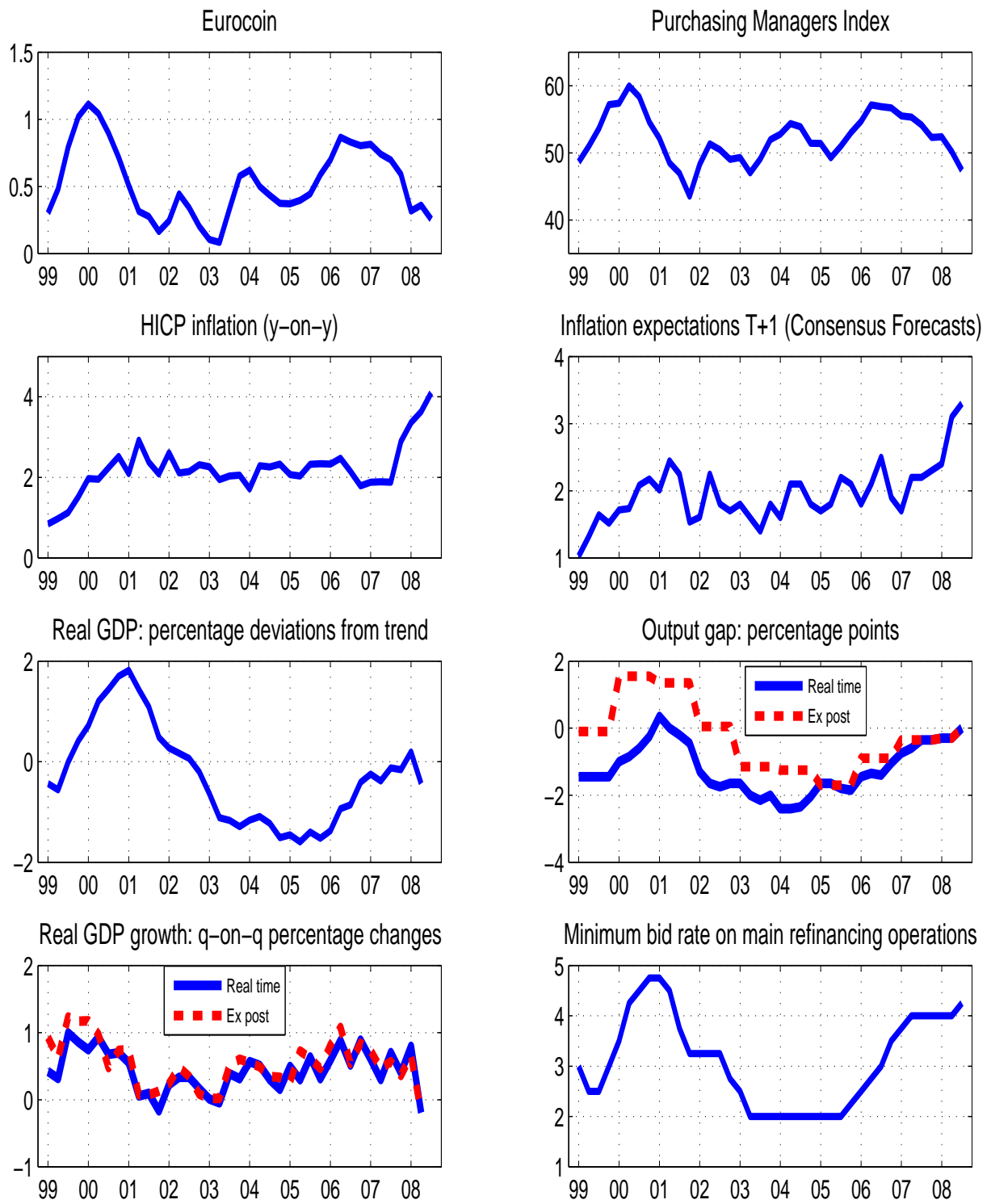


Figure 1 - Data

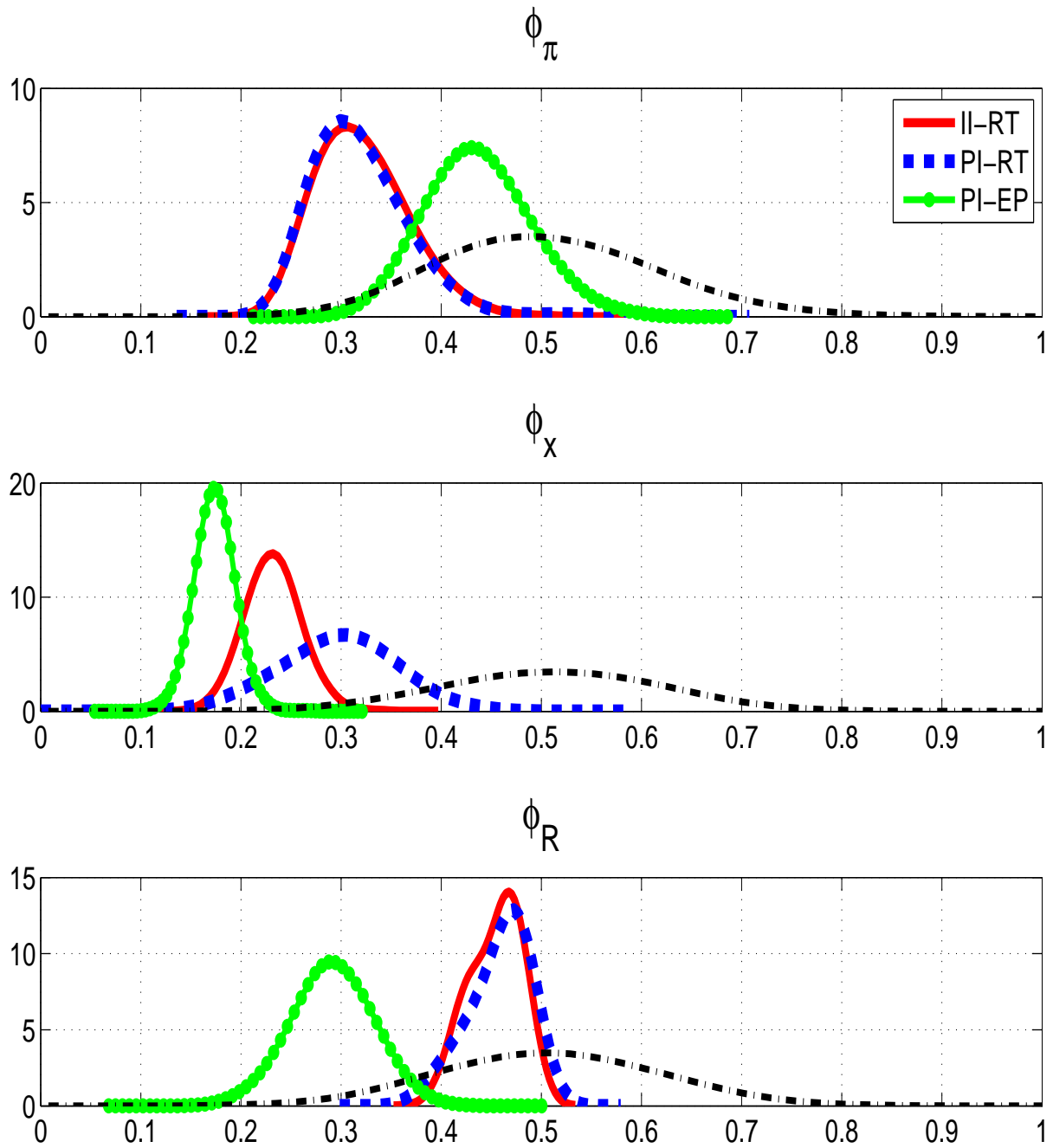


Figure 2 - Prior and posterior marginal distributions

*Note:* The marginal posterior distributions are computed using 200,00 draws from the Metropolis algorithm.

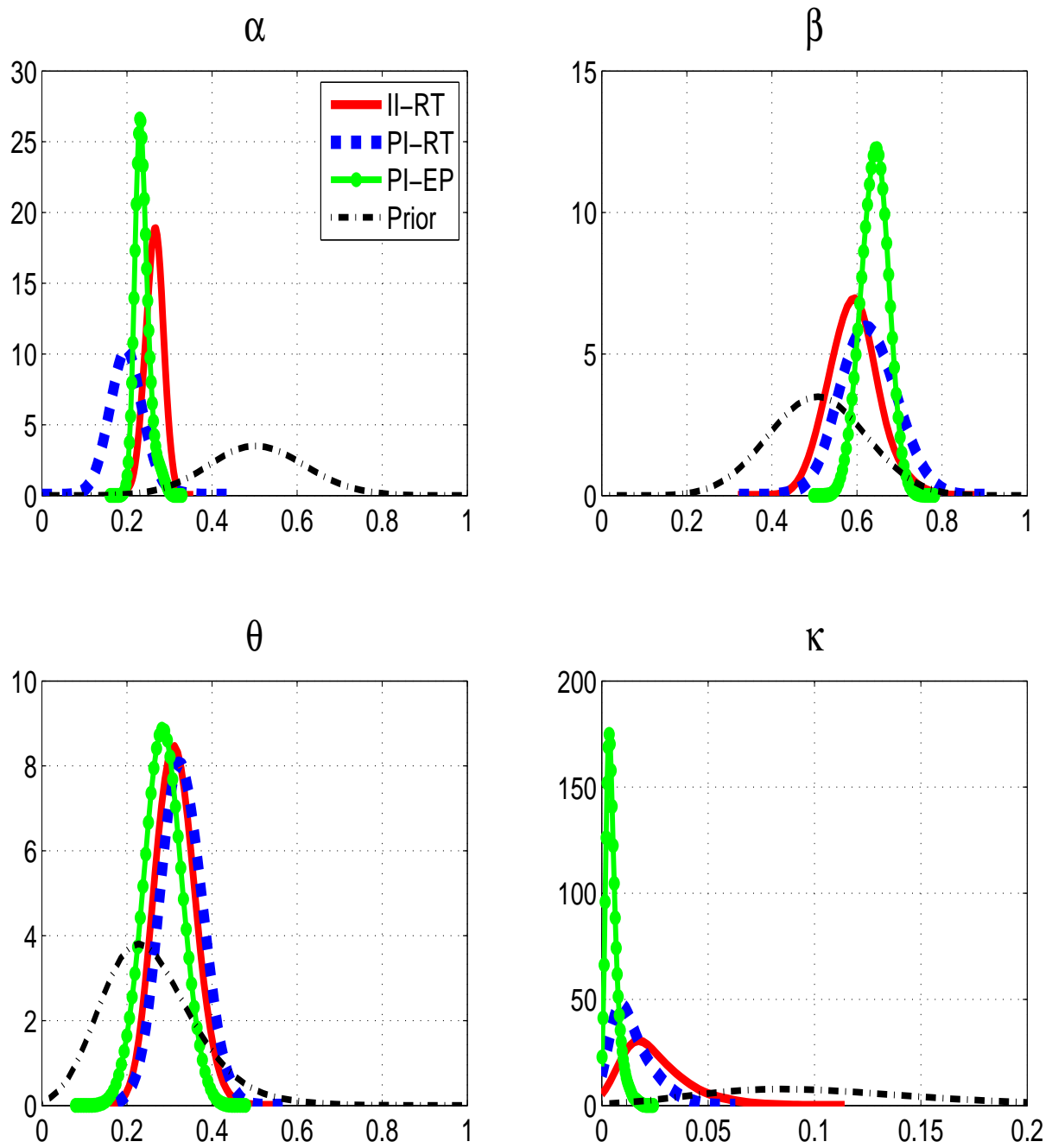


Figure 3 - Prior and posterior marginal distributions

*Note:* The marginal posterior distributions are computed using 200,00 draws from the Metropolis algorithm.

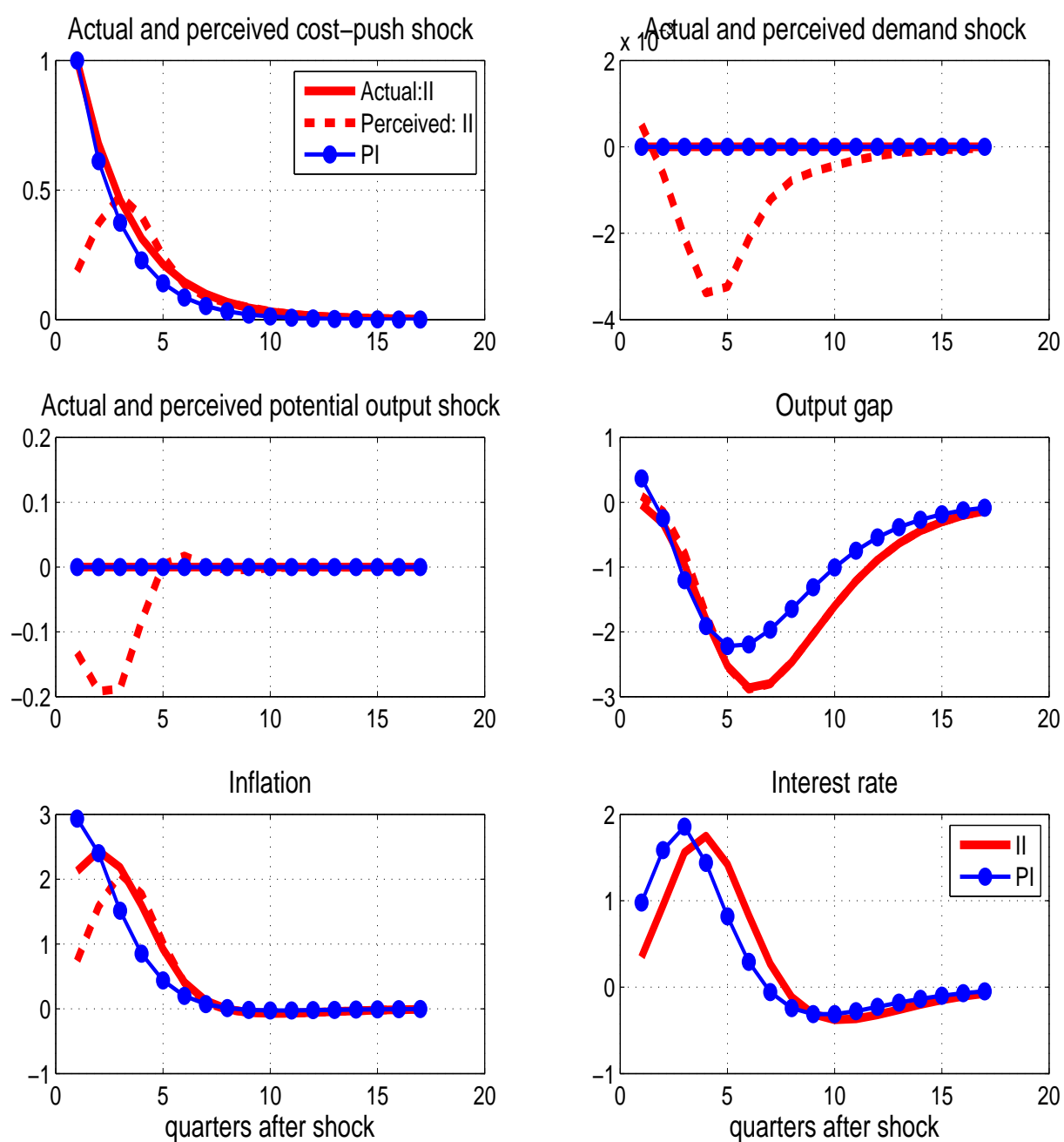


Figure 4 - Impulse responses to a positive cost-push shock

*Note:* The impulse responses are computed using the median of the marginal posterior distributions of the parameters.

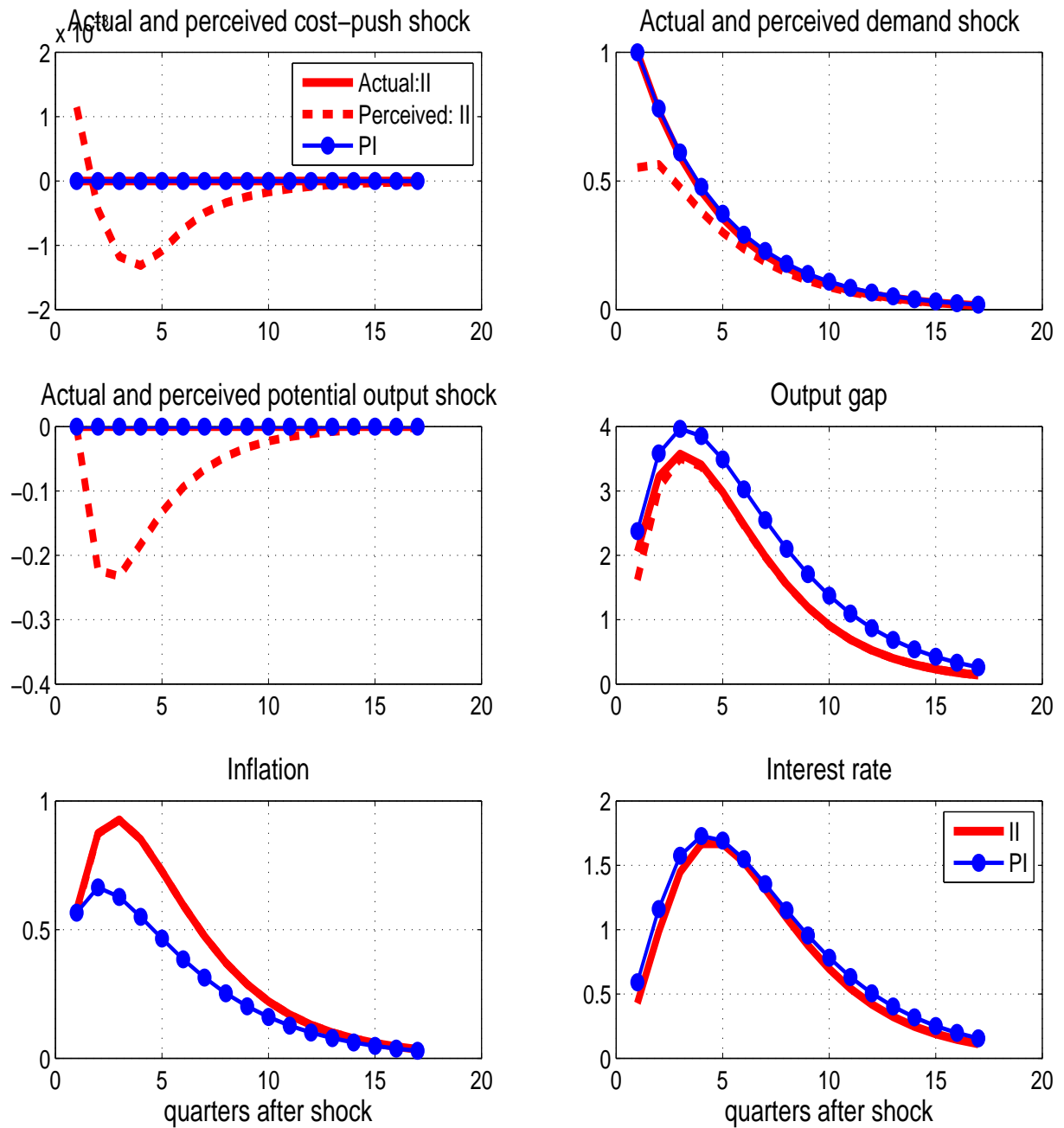


Figure 5 - Impulse responses to a positive demand shock

*Note:* The impulse responses are computed using the median of the marginal posterior distributions of the parameters.

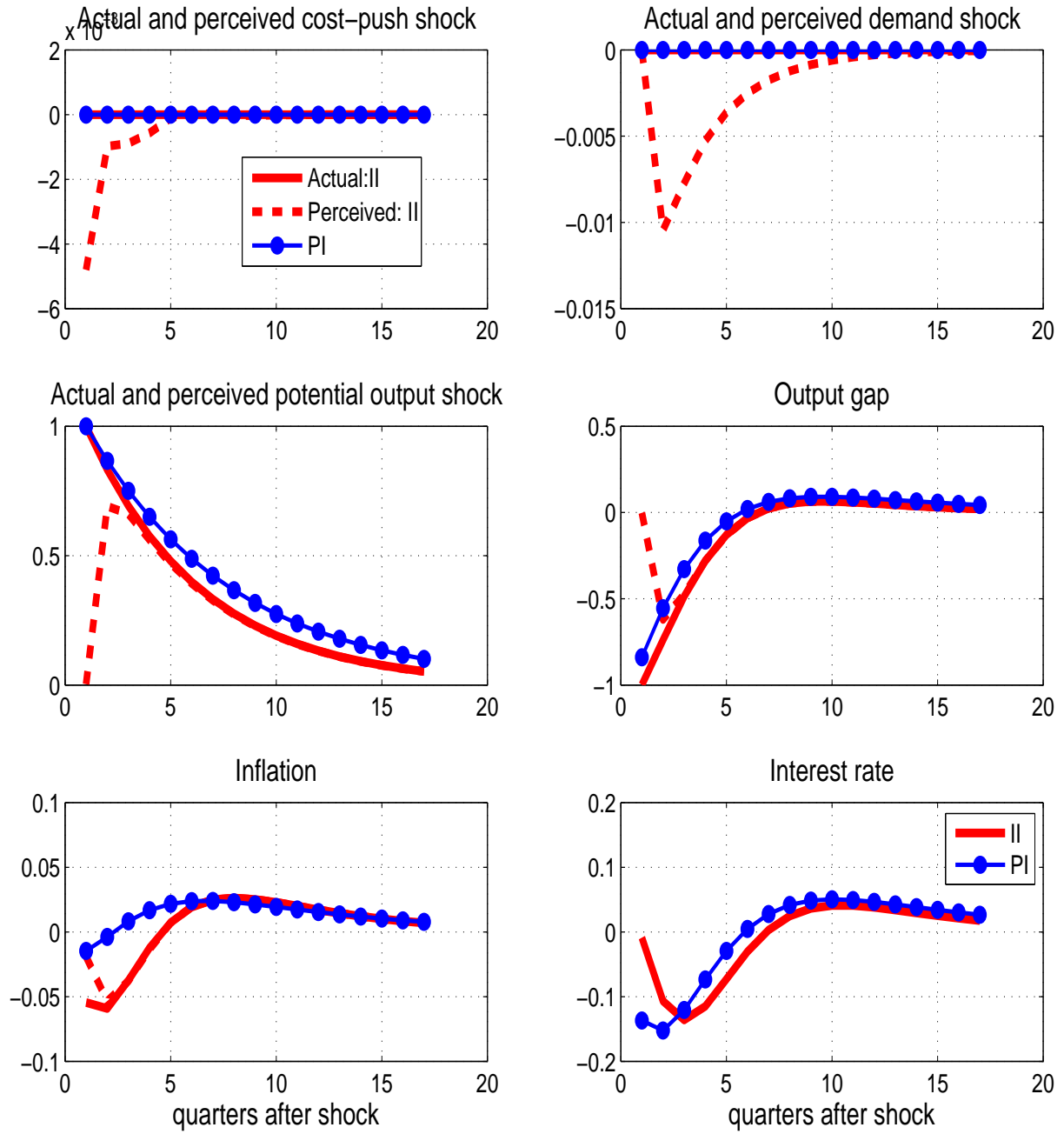


Figure 6 - Impulse responses to a positive shock to potential output

*Note:* The impulse responses are computed using the median of the marginal posterior distributions of the parameters.

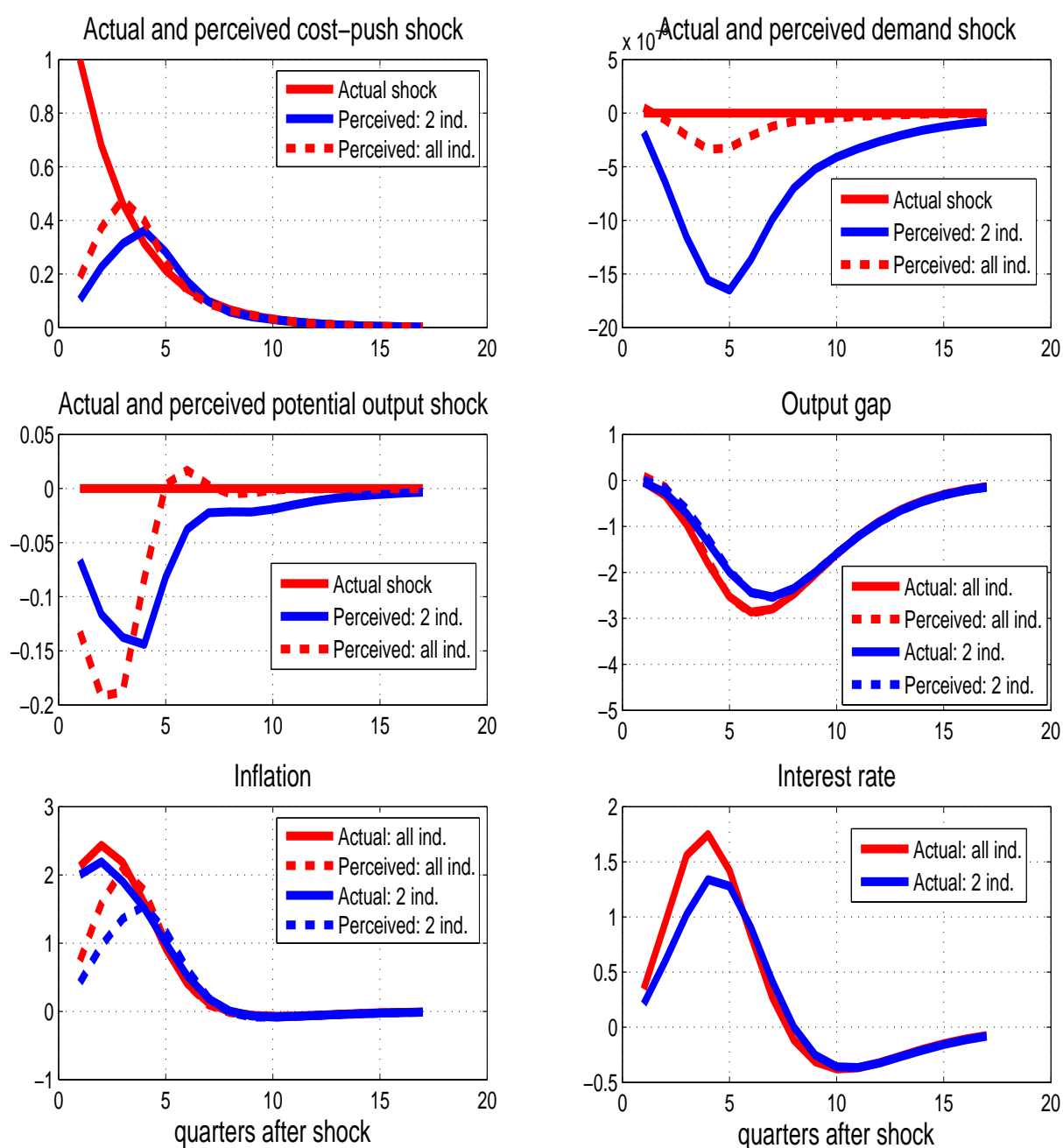


Figure 7 - Impulse responses to a positive cost-push shock

*Note:* The impulse responses are computed using the median of the marginal posterior distributions of the parameters. The case with two indicators refers to the model in which agents have access only to current inflation and the output gap.

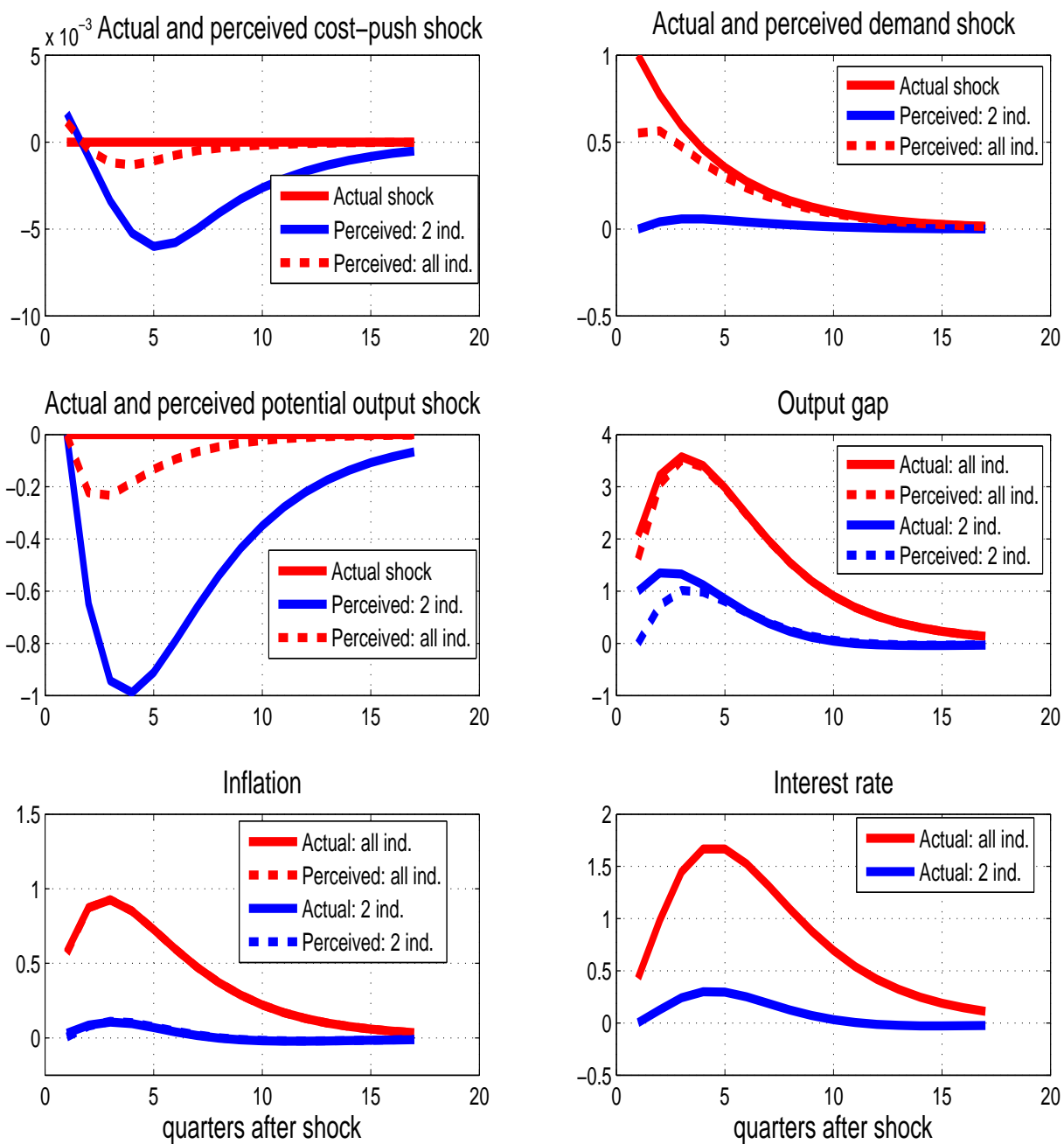


Figure 8 - Impulse responses to a positive demand shock

*Note:* The impulse responses are computed using the median of the marginal posterior distributions of the parameters. The case with two indicators refers to the model in which agents have access only to current inflation and the output gap.

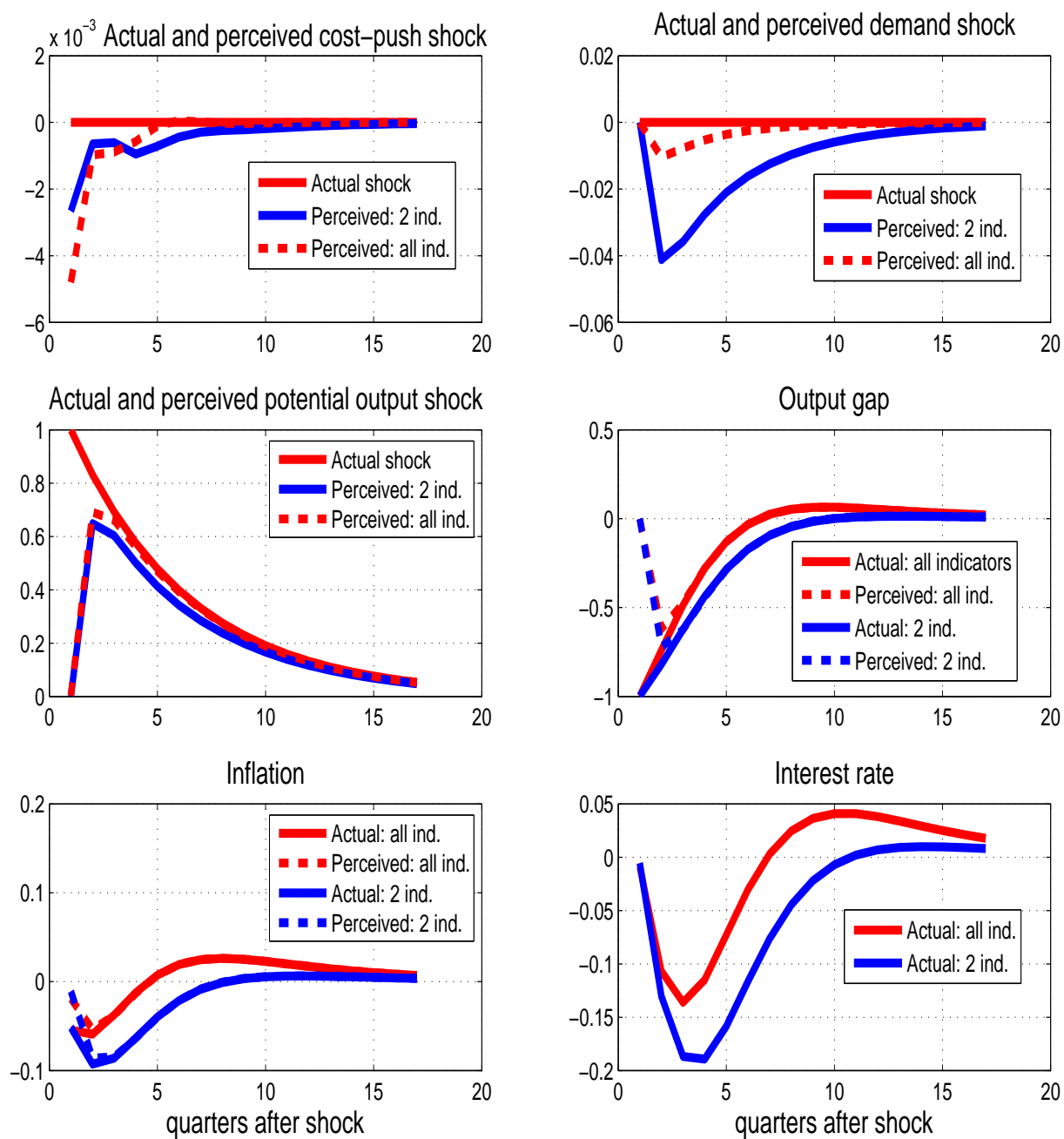


Figure 9 - Impulse responses to a positive shock to potential output

*Note:* The impulse responses are computed using the median of the marginal posterior distributions of the parameters. The case with two indicators refers to the model in which agents have access only to current inflation and the output gap.

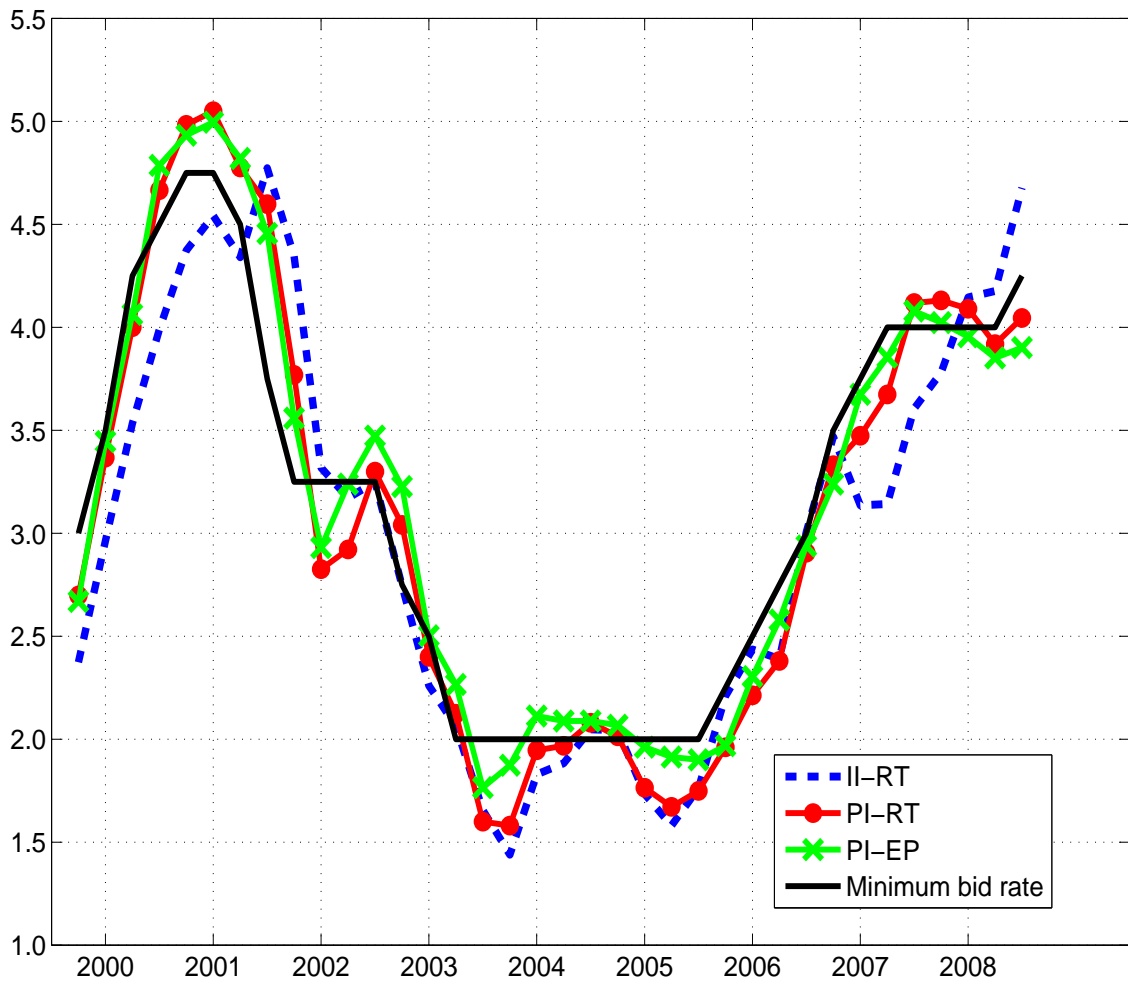


Figure 10 - Minimum bid rate (MBR) predicted by the Taylor rule

*Note:* The interest rate predicted by the Taylor rule are computed using the median of the marginal posterior distributions of the parameters.

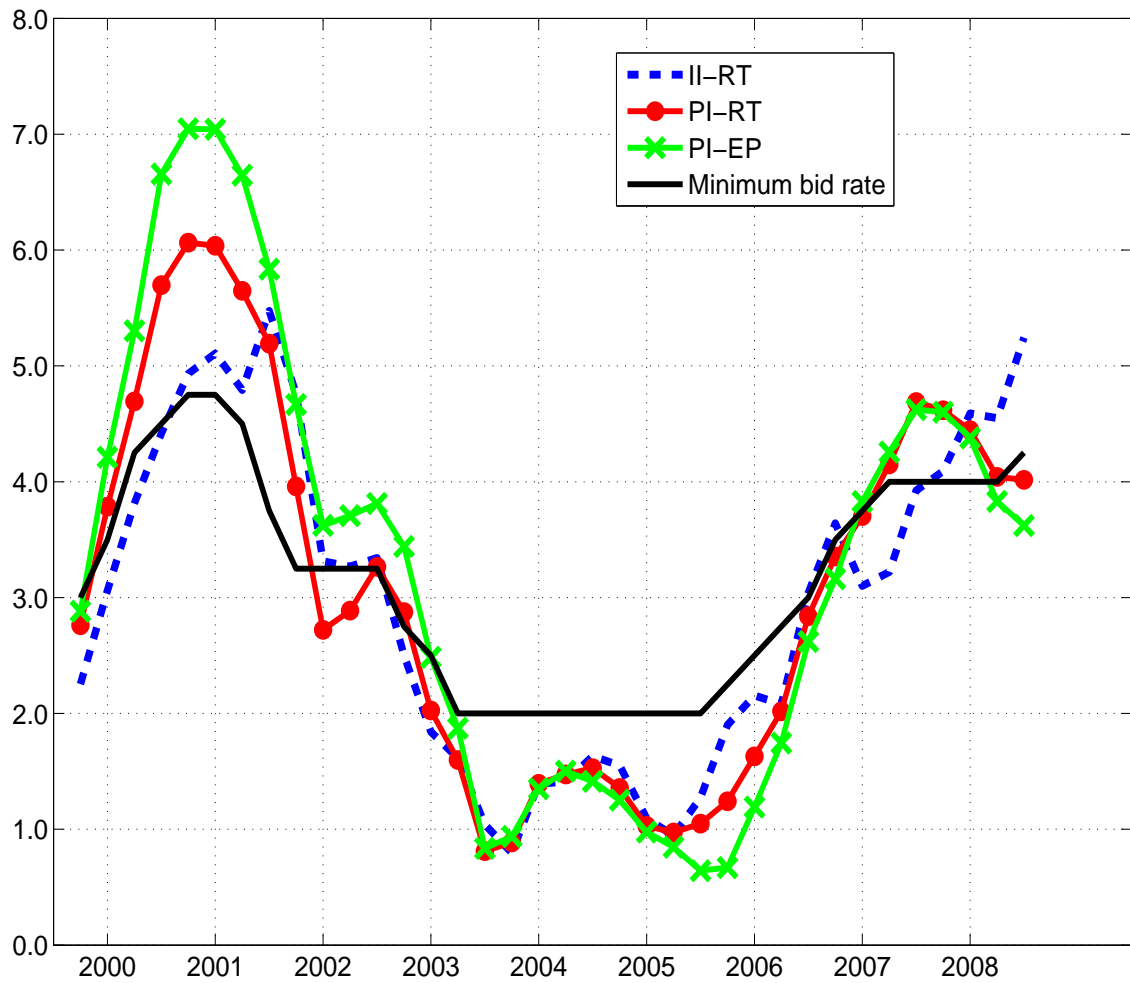


Figure 11 - Minimum bid rate (MBR) predicted by the optimal policy under discretion

*Note:* The interest rate predicted by the optimal policy under discretion are computed using the median of the marginal posterior distributions of the parameters. The weights in the loss function  $\nu_x$  and  $\nu_R$  are set, respectively, to 0.25 and 2.0.

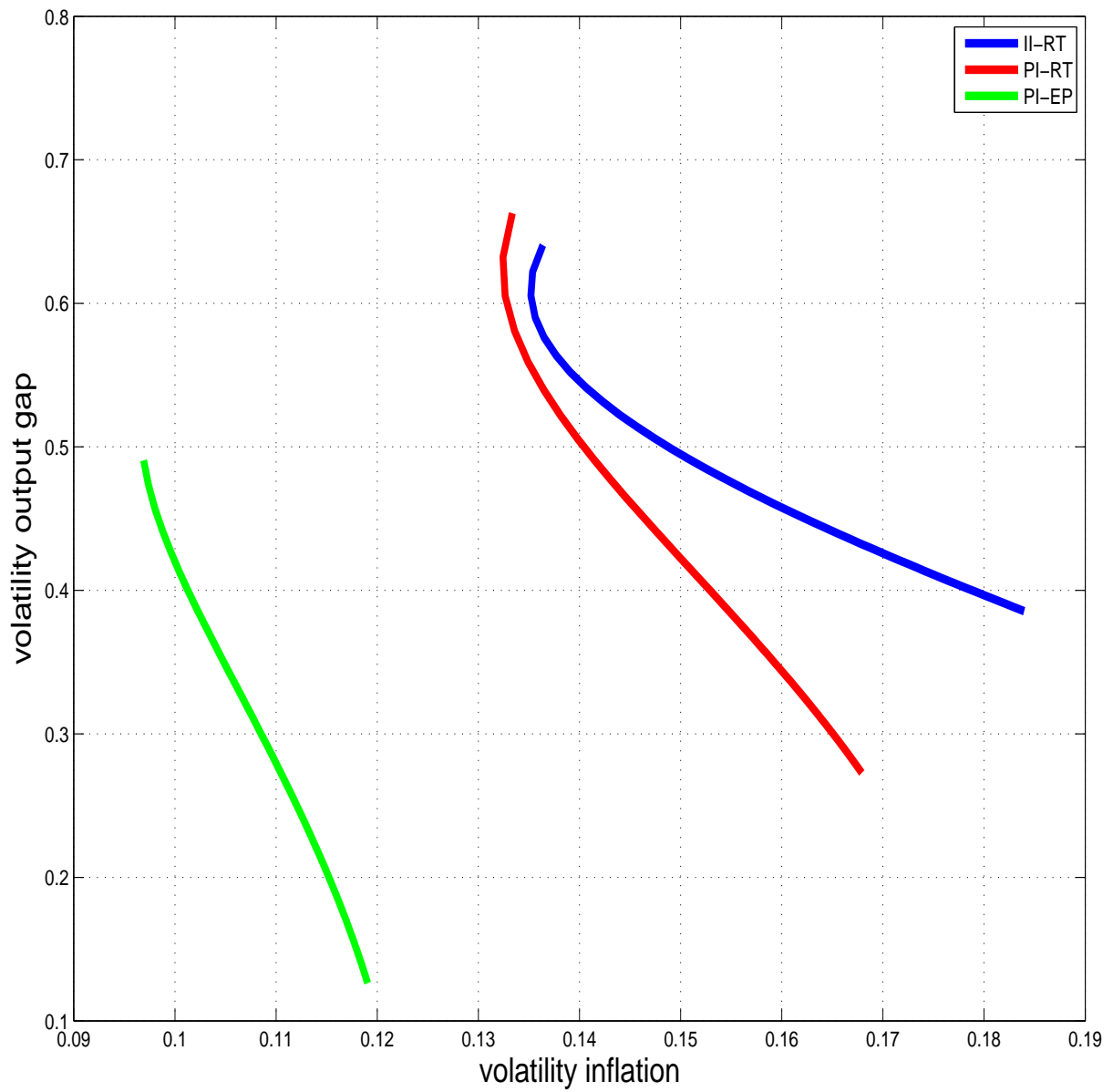


Figure 12 - Output gap - inflation volatility frontier: Taylor rule

*Note:* The frontiers are computed by varying the coefficient  $\phi_x$  and keeping all the other parameters fixed at the median of their marginal posterior distributions.

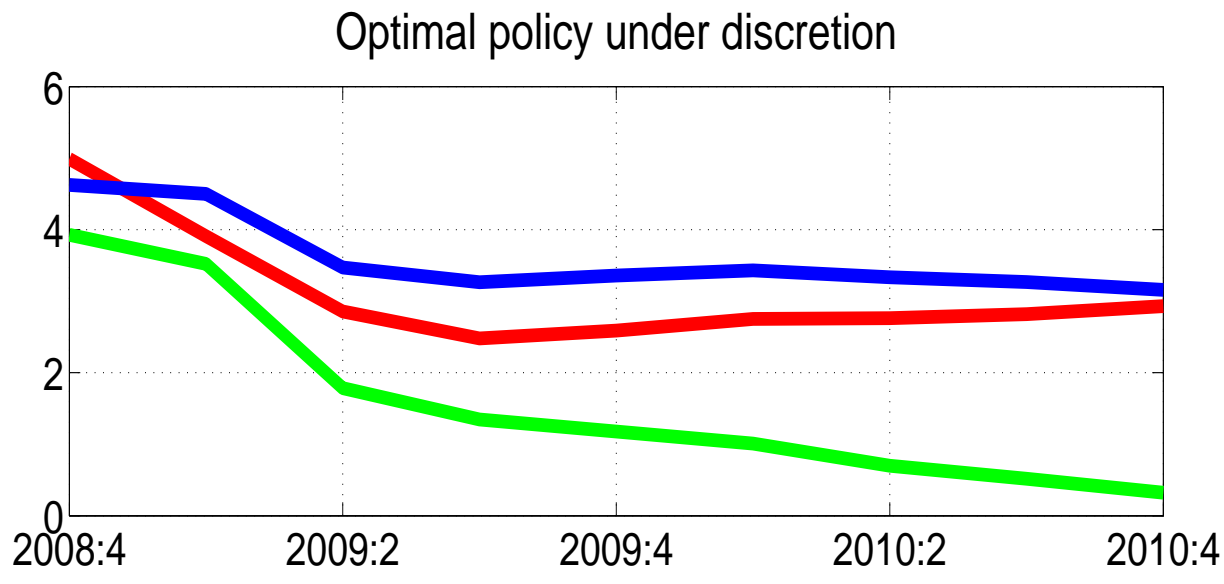
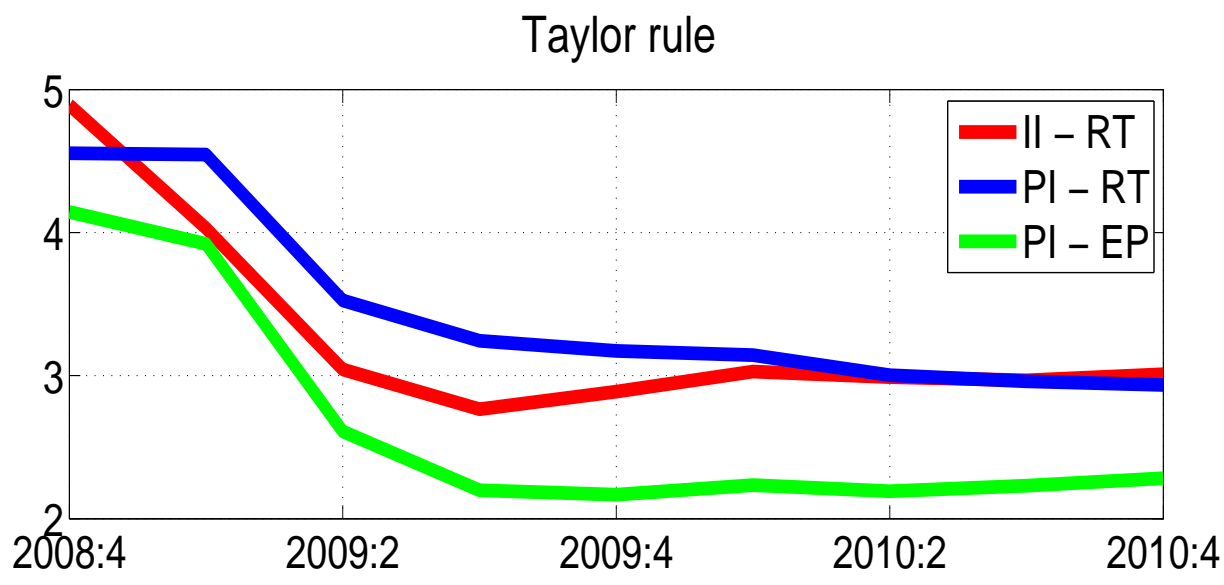


Figure 13 - Projection of the minimum bid rate: Taylor rule (top panel) and optimal policy under discretion (bottom panel)

*Note:* The interest rate predicted by the optimal policy under discretion are computed using the median of the marginal posterior distributions of the parameters.

[TO BE COMPLETED]

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