Disinflationary shocks and inflation target uncertainty

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Abstract

Euro-area inflation has been constantly falling in 2013 and 2014, reaching negative figures. This paper studies how the uncertainty surrounding the inflation target of the central bank amplifies the effects of transitory shocks to inflation, in particular when monetary policy is constrained in its actions, for example by the zero lower bound. The analysis shows that the larger is the uncertainty around the inflation target, the more contractionary and longer lasting are the effects of a transitory shock to inflation. These effects are larger when the central bank cannot adjust the short-term rate.

Keywords: inflation target; imperfect information; monetary policy.

JEL classification codes: E31; E52; E58.

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Question*: Professor Issing, what does "close to 2%" mean in the definition of price stability? Is it a little bit less than 2%, on average, in the medium term or is it a pure inflation target now?*

Issing*: [...] And second, this "close to 2%" is not a change, it is a clarification of what we have done so far, what we have achieved – namely inflation expectations remaining in a narrow range of between roughly 1.7% and 1.9% – and what we intend to do in our forward-looking monetary policy.*

O. Issing, Member of the Executive Board of the ECB[1]

1. Introduction and motivation

In the post global financial crisis world, low inflation characterizes several economies. In 2014 fourteen OECD countries out of 34 had annual headline inflation above one per cent; in the last quarter of the year only ten. In the same quarter core inflation was above 1 per cent in sixteen countries. In almost all these countries the central bank has an explicit inflation target; in the largest economies monetary policy is constrained by the zero lower bound to policy rates.

An explicit target can help anchoring inflation expectations. Gürkaynak, Levin, and Swanson (2006) provide evidence that market-based measures of inflation expectations are less sensitive to macroeconomic news in those countries in which the monetary policy framework is characterized by an inflation targeting (IT) regime. Capistrán and Ramos-Francia (2007) show that in inflation targeting regimes inflation forecasts from professional forecasters are less dispersed than in non-IT countries. Johnson (2002) finds, instead, that inflation targeting does not affect the dispersion of forecasts after accounting for the effects of past inflation rates.

An abundant strand of the macroeconomic literature has studied monetary policy under rational expectations and perfect central bank credibility. A well-established results is that a central bank committed to delivering a given inflation target can successfully steer expectations in the face of inflationary disturbances and hence stabilize the economy.

A less crowded strand of the literature has studied the macroeconomic implications of imperfect information on the inflation target. Erceg and Levine (2003) shows that when private agents have limited information about the central bank's objectives, disinflation can generate substantial output costs. Branch and Evans (2013) develop a model in which agents have imperfect information about the inflation target of the central bank and form expectations using discounted least squares. If inflation drifts downward, agents' inflation

[1] Press seminar on the evaluation of the ECB's monetary policy strategy, Frankfurt, 8 May 2003.

expectations will decrease feeding back into lower inflation, in a self-reinforcing process. Busetti, Ferrero, Gerali and Locarno (2014) also find similar results. Darracq Pariès and Moyen (2013) study the consequences of imperfect credibility of the central bank on the anchoring of long-term expectations. In a standard DSGE model, price and wage setters are uncertain about the determination of the central bank to maintain a fixed inflation objective in the face of inflationary shocks. Imperfect credibility increases the volatility of inflation and the output gap.

In this paper we use a small-scale DSGE model to assess how the degree of uncertainty surrounding the inflation target affects the transmission of shocks to inflation, in particular when monetary policy is constrained by the zero lower bound to policy rates. Our analysis is motivated by the recent evolution of long-term inflation expectations in the U.S. (figure 1) and the euro area (figure 2).[2]

Panels a) and b) of Figure 1 show the evolution of the mean and the median of the five-year inflation expectations five-year ahead across analysts. According to both measures, expectations started increasing in the second half of 2008, at the peak of the global financial crisis. Also the volatility increased markedly, reaching a maximum of 1.1 percentage points in mid-2011. In January 2012 the Federal Open Market Committee (FOMC) clarified that, within its dual mandate, the long-run target for inflation is set at two per cent.[3] In the subsequent quarters the volatility of longer-term inflation expectations almost halved (panel c) and the distribution became more symmetric (panel d); the mean progressively decline reaching 2.1 per cent in the last quarter of 2014.[4] Interestingly, in the fourth quarter of 2007 a special question was asked to forecasters, with the aim of assessing their understanding of the inflation target of the FOMC. The majority of the respondents answered that the FOMC had a target for core PCE between 1.5 and 2.2.

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[2] A comparison of the degree of anchoring of longer-term inflation expectations in the U.S. and the euro area for the period between up to 2007 is carried out in Beechey, Johannsen, and Levin (2011). The authors compare the evolution of inflation expectations using both financial market prices and surveys and show that until 2007 long-run inflation expectations were more dispersed in the U.S. than in the euro area, suggesting a larger degree of anchoring in the latter economy.

[3] From the press conference following the FMOC meeting of 24-25 January 2012: "*The inflation rate over the longer run is primarily determined by monetary policy, and hence the Committee has the ability to specify a longer-run goal for inflation. The Committee judges that inflation at the rate of 2 per cent, as measured by the annual change in the price index for personal consumption expenditures, is most consistent over the longer run with the Federal Reserve's statutory mandate*."

[4] The definition of the inflation goal does not specify, however, whether exceeding above or below is equally worrying for the FOMC. From the minutes of the FOMC meeting of 28-29 October 2014: "[...] On the specific issues, there was widespread agreement that inflation moderately above the Committee's 2 per cent goal and inflation the same amount below that level were equally costly—and many participants thought that that view was largely shared by the public."

The objective of the ECB is to maintain price stability in the medium term, in accordance with Article 127 (1) of the Treaty on the Functioning of the European Union. In October 1998 the Governing Council defined price stability as "as a year-on-year increase in the Harmonised Index of Consumer Prices (HICP) for the euro area of below 2%." In May 2003 the Governing Council reviewed the monetary policy strategy of the ECB and clarified that "[…] in the pursuit of price stability, it aims to maintain inflation rates below, but close to, 2% over the medium term". The quotation at the beginning of this Introduction suggests that the ECB has a target between 1.7 and 1.9 per cent.

Panels a) and b) of Figure 2 show the evolution of the mean and the median of the five-year inflation expectations. Both measures depict a similar picture. At the beginning of 2012 inflation expectations stood at 2.0 per cent, on average across forecasters. Since the summer of 2012 inflation expectations have persistently declined, reaching 1.77 per cent in the first quarter of 2015. In a special survey conducted on the occasion of the fifteenth anniversary of the SPF's launch in January 1999, participants were asked, among several questions, which type of information they typically used to form longer-term inflation expectations. Most respondents answered that they relied on the ECB's inflation objective, trends in actual inflation (54%) and longer-term market-based expectations.[5] The uncertainty surrounding long-term expectations, measured by either the standard deviation of the point estimates across forecasters (red line; panel c) or by the mean of the standard deviations indicated by the individual forecasters (blue line; panel c) constantly declined or remained stable from the beginning of 1999 until the end of 2008. Since then, both measures of uncertainty have increased persistently and remained above the values prevailing before the global financial crisis. The degree of asymmetry has been volatile throughout the whole period.

Some commentators of the ECB have argued that the asymmetry in the definition could be an issue if inflation falls persistently below the target, in particular since it limits the ability of monetary policy to counteract deflationary risks. Fatas (2014) argues that the asymmetry implied by the ECB mandate should be reversed.[6] Inflation should be close to but above 2 per cent and this should lead to a very strong reaction when inflation is persistently below the 2 per cent target. Along a similar line, Ubide (2014) argues that the

[5] See "Results of the second special questionnaire for participants in the ECB Survey of Professional Forecasters" at http://www.ecb.europa.eu/stats/prices/indic/forecast/shared/files/resultssecondspecialquestionnaireecbsurveyspf201401en.pdf??92f09eaa6906c6e15bf77fb4dcdd055f

[6] See http://knowledge.insead.edu/blog/insead-blog/ecb-should-aim-higher-on-inflation-3664.

ECB's definition of price stability is less precise than that employed by other central banks, and some members of the Governing Council may interpret the definition as setting a ceiling, rather than a target for inflation. He suggests that the ECB should clarify the definition of price stability, by explicitly stating that deviations above and below this objective will be treated equally; this would eliminate any ambiguity, strengthen the anti-deflation stance, and help push inflation expectations back towards 2 per cent. Interestingly this proposal has been also discussed within the FOMC (see footnote 3).[7]

The evidence on the degree of uncertainty around central banks' target for inflation motivates our analysis. In this paper we use a small-scale DSGE model to assess how the degree of uncertainty surrounding the inflation target affects the transmission of shocks to inflation, in particular when monetary policy is constrained by the zero lower bound.

The key results of our analysis are the following. When agents and the central bank have imperfect information regarding the state of the economy – including, in particular, the central bank's inflation target – cost-push shocks can have considerably different effects compared to the case with perfect information. A favourable cost-push shock that would raise output in the latter case, turns out to have negative effects on output, as agents perceive that also a negative demand shock and a negative shock that temporarily reduces the inflation target may have occurred. In this framework, the central bank reduces the nominal interest rate less strongly, effectively raising the real short-term interest rate. The larger is the uncertainty around the inflation target, the more contractionary is a transitory shock to inflation. The larger the weight attached to the central bank target in firms' price setting the more contractionary the effects of cost-push shocks are. These effects turn out to be larger when the central bank cannot adjust the short-term rate.

The reminder of the paper is organized as follows. Section 2 presents the model. Section 3 discusses the results and Section 4 presents some robustness analyses. Section 5 draws the conclusions and suggests possible future research.

[7] Hayo and Neuenkirch (2014) use a survey conducted by Barclays Europe between 17 April and 1 May 2013 among the subscribers to Barclay's fixed income newsletter. The results show that the Federal Reserve is perceived as the most credible central bank; the Bank of England ranks second, followed by the Bank of Japan and the ECB. However, respondents living in Europe (excluding the UK) perceive the ECB as more credible than those living in the rest of the world.

2. A small-scale DSGE model

In this section we describe the features of a small-scale new Keynesian DSGE model that we use for the purposes of our analysis. The model economy consists of a representative household, a representative finished-goods-producing firm, a continuum of intermediate-goods-producing firms and a central bank. For many aspects the model is similar to Clarida et al. (1999), Galí (2003) and Woodford (2003). The two main differences pertain to a generalization of the quadratic adjustment cost mechanism a la Rotemberg (1982) to model nominal price stickiness and to the presence of a time-varying inflation target. Finally, the model is solved under two alternative information settings regarding the knowledge of the state of the economy: either under perfect information (PI) or under imperfect information (II) as in Svensson and Woodford (2003).

The representative household

The representative households lives forever and her expected lifetime utility is

$$E_0 \sum_{t=0}^{\infty} \beta^t \{log(C_t - \gamma C_{t-1}) - H_t\} \, d_t \tag{1}$$

where E_0 is the expectation operator conditional on time $t=0$ information and $\beta \in (0,1)$ is the subjective rate of time preference. The instantaneous utility function is increasing in the consumption of a final good (C_t) relative to a level γ of external habit defined in terms of lagged aggregate consumption $(\bar{C}_{t-1})$ and decreasing in labour (H_t). Finally, d_t represents a preference shock that evolves according to $\log(d_t) = \rho_d \log(d_{t-1}) + \varepsilon_{d,t}$, with $\rho_d \in [0,1)$ and $\varepsilon_{d,t} \sim N(0, \sigma_d^2)$.

At a given period t, the representative household faces the following nominal flow budget constraint:

$$P_t C_t + B_t \leq P_t w_t H_t + (1 + i_{t-1}) B_{t-1} + F_t \tag{2}$$

where P_t is the price of the final good, B_t represents holding of bonds offering a one-period nominal return i_t, w_t is the real wage, and F_t are firms' profits that are returned to households. The representative household's problem is to maximize (1) subject to the sequence of budget constraints (2), yielding the following first order conditions:

$$u_{c,t} = (C_t - \gamma \bar{C}_{t-1})^{-1} d_t \tag{3}$$

$$d_t = u_{c,t} w_t \tag{4}$$

$$u_{c,t} = \beta(1 + i_t)E_t\left(\frac{u_{c,t+1}}{P_{t+1}/P_t}\right) \tag{5}$$

where $u_{c,t}$ is the marginal utility of consumption. Equations (3)-(5) have the usual economic interpretation.

Final Good Producers

In each period a final good Y_t is produced by perfectly competitive firms using a continuum of intermediate inputs $Y_{i,t}$ indexed by $i \in (0,1)$ and a standard CES production function:

$$Y_t = \left[\int_0^1 Y_{i,t}^{(\theta-1)/\theta} di\right]^{\theta/(\theta-1)} \tag{6}$$

with $\theta > 1$. Taking prices as given the final good producer chooses intermediate good quantities $Y_{i,t}$ to maximise profits, resulting in the usual demand schedule:

$$Y_{i,t} = \left(\frac{P_{i,t}}{P_t}\right)^{-\theta} Y_t \tag{7}$$

The zero profit condition of final good producers leads the aggregate price index:

$$P_t = \left[\int_0^1 P_{i,t}^{1-\theta} di\right]^{1/(1-\theta)}. \tag{8}$$

Intermediate Goods Producers

Intermediate inputs $Y_{i,t}$ are produced by a continuum of firms indexed by $i \in (0,1)$ with technology:

$$Y_{i,t} = H_{i,t}. \tag{9}$$

Prices are sticky, with intermediate goods producers in monopolistic competition setting prices according to a generalized quadratic adjustment cost mechanism a la Rotemberg (1982). As in Ireland (2007), we assume that the quadratic adjustment cost, measured in terms of the final good, is given by the following specification:

$$\Gamma_{i,t} = \frac{\phi}{2}\left\{\frac{P_{i,t}}{[\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}]P_{i,t-1}} - 1\right\}^2 Y_t \tag{10}$$

where $\phi \geq 0$ governs the magnitude of the adjustment cost, $\Pi_t \equiv P_t/P_{t-1}$ so that Π_{t-1} denotes the gross inflation rate between periods t − 2 and t − 1, Π_t^* denotes the central bank's time-varying inflation target for period t, and the parameter $\alpha \in (0,1)$ determines to what extent intermediate firms' price setting is backward instead of forward looking. In particular, when $\alpha = 0$, so that firms find it costless to adjust their prices in line with the central bank's inflation target, the model's Phillips curve relation becomes purely forward looking. At the opposite extreme, when $\alpha = 1$, so that firms find it costless to adjust their prices in line with the previous period's inflation rate, the backward looking term in the Phillips curve becomes approximately equal in importance to the forward-looking term. Notice that according to (10) prices are fully indexed and thus there are not distortionary effects stemming from positive levels of steady-state inflation.[8]

The problem for the intermediate firm *i* is then:

$$\max_{\{P_{i,t}\}_{t=0}^{\infty}} E_t \sum_{j=0}^{\infty} \frac{\beta^j u_{c,t+j}}{u_{c,t}} \left\{ \frac{P_{i,t+j}}{P_{t+j}} Y_{i,t+j} - MC_{i,t+j}^r Y_{i,t+j} - \Gamma_{i,t+j} \right\} \tag{11}$$

$$\text{subject to: } Y_{i,t+j} = \left[\frac{P_{i,t+j}}{P_{t+j}}\right]^{-\theta} Y_{t+j}$$

where $MC_{i,t+j}^r = w_{t+j}$ is the real marginal cost function. Intermediate firms can change their price in each period, subject to the payment of the adjustment cost. Therefore, all the firms face the same problem, and thus will choose the same price and output: $P_{i,t} = P_t$ and $Y_{i,t} = Y_t$ for every *i*. Hence, exploiting the symmetry of the equilibrium, the first-order condition for the above maximization problem yields:

$$\theta - 1 = \theta w_t - \phi \left[\frac{\Pi_t}{\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}} - 1\right] \frac{\Pi_t}{\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}} +$$

$$(12)$$

$$+\beta \frac{u_{c,t+1}}{u_{c,t}} \phi \left[\frac{\Pi_{t+1}}{\Pi_t^{\alpha}(\Pi_{t+1}^*)^{1-\alpha}} - 1\right] \frac{\Pi_{t+1}}{\Pi_t^{\alpha}(\Pi_{t+1}^*)^{1-\alpha}} \frac{Y_{t+1}}{Y_t}.$$

Central bank

The central bank conducts monetary policy according to a generalized Taylor (1993) rule given by:

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[8] See, e.g. Ascari and Ropele (2009).

$$1+\mathrm{i}_t=(1+\bar{\mathrm{\imath}})\left(\frac{1+\mathrm{i}_{t-1}}{1+\bar{\mathrm{\imath}}}\right)^{\phi_i}\left(\frac{\Pi_t}{\Pi_t^*}\right)^{(1-\phi_i)\phi_\pi}\left(\frac{Y_t}{\bar{Y}}\right)^{(1-\phi_i)\phi_y} \tag{13}$$

where $\phi_i \in [0,1]$, $\phi_\pi \in [0,\infty)$ and $\phi_y \in [0,\infty)$. According to (13) the central bank increases the short-term nominal interest rate i_t whenever the inflation rate rises above its target Π_t^* and/or when the level of output is above its steady-state level Y. Provided that $\phi_i \in (0,1]$ the monetary policy rule exhibits an inertial behaviour. As in Ireland (2007) a novel feature of the generalized Taylor rule (13) is the fact that the central bank's inflation target Π_t^* is time-varying. We assume that the target evolves according to the following exogenous AR(1) process:

$$\log(\Pi_t^*)=(1-\rho_\Pi)\log(\Pi^*)+\rho_\Pi\log(\Pi_{t-1}^*)+\varepsilon_{\Pi,t} \tag{14}$$

where Π^* represents the long-run inflation target, $\rho_\Pi \in (0,1)$ and $\varepsilon_{\Pi,t}\sim N(0,\sigma_{\pi^*}^2)$. So, unlike Ireland (2007) where the central bank is allowed to systematically adjust its inflation target in response to the structural shocks hitting the economy, here we simply assume that inflation target to vary exogenously in response to realizations of the disturbance $\varepsilon_{\Pi,t}$. As discussed more fully in Section 4, we will assume a very small value for $\sigma_{\pi^*}^2$ and a value close to one for ρ_Π so that the inflation target does not exhibit too frequent variations.

Aggregate resource constraint

It is important to note that the Rotemberg quadratic adjustment cost model creates an inefficiency wedge between aggregate output and aggregate consumption. In particular the aggregate resource constraint

$$\mathrm{Y}_t=\mathrm{C}_t+\frac{\phi}{2}\left\{\frac{\Pi_t}{[\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}]}-1\right\}^2 Y_t \tag{15}$$

can be easily rewritten as

$$\mathrm{Y}_t=\left\{1-\frac{\phi}{2}\left\{\frac{\Pi_t}{[\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}]}-1\right\}^2\right\}^{-1}\mathrm{C}_t \tag{16}$$

Note that absent any price indexation, i.e. $\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}\equiv 1$, the inefficiency wedge would increase with inflation: the higher inflation, the higher the size of the price change and hence the higher the adjustment costs that firms have to pay. However, with the full price indexation mechanism that we have assumed this inefficiency wedge washes out both in steady state and when (log-) linearly approximating the model.

2.1 The log-linearized model

We now present the log-linearized version of the model approximated around the deterministic steady state.[9] Throughout, for any variable x_t we let $\hat{x}_t = \log(X)/\log(\bar{X})$.

The linearized model is given by the following set of equations:

$$\frac{1+\gamma}{1-\gamma}\hat{y}_t = \frac{\gamma}{1-\gamma}\hat{y}_{t-1} + \frac{1}{1-\gamma}y_{t+1|t} - \left(\hat{\imath}_t - \hat{\pi}_{t+1|t}\right) + (1-\rho_d)\hat{d}_t \tag{23}$$

$$(1+\alpha\beta)\hat{\pi}_t = \alpha\hat{\pi}_{t-1} + \beta\hat{\pi}_{t+1|t} + \frac{1}{\phi}\left(\frac{\theta-1}{1-\gamma}\right)(\hat{y}_t - \gamma\hat{y}_{t-1}) + (1-\alpha)(1-\beta\rho_\Pi)\hat{\pi}_t^* + \hat{s}_t \tag{24}$$

$$\hat{\imath}_t = \phi_i\hat{\imath}_{t-1} + (1-\phi_i)\left[\phi_\pi(\hat{\pi}_t - \hat{\pi}_t^*) + \phi_y\hat{y}_t\right] \tag{25}$$

$$\hat{d}_t = \rho_d\hat{d}_{t-1} + \varepsilon_{d,t} \tag{26}$$

$$\hat{s}_t = \rho_s\hat{s}_{t-1} + \varepsilon_{s,t} \tag{27}$$

$$\hat{\pi}_t^* = \rho_\pi\hat{\pi}_{t-1}^* + \varepsilon_{\pi,t} \tag{28}$$

Several comments are in order. Equation (23) is a standard *hybrid* IS curve in which current output depends positively on lagged and next period's expected output levels and is inversely related to the ex-ante real interest rate. As the parameter γ increases the degree of persistence of output rises. The IS curve is also subject to the preference shock that acts as a demand shifter. Equation (24) is a hybrid new-Keynesian Phillips curve (NKPC) where current inflation is a function of past and future expected inflation and also of current output.

Two remarks are in order. First, the time-varying inflation target enters the hybrid NKCP with a positive coefficient. This is the result of the indexation scheme that we postulated in the previous section whereby past prices automatically increase by a factor that depends on Π_t^*, as long as $\alpha \neq 1$. Hence a decline in the inflation target will exert an outright decreasing effect on inflation. Second, the hybrid NKPC has been augmented by an ad-hoc cost-push shock $\hat{s}_t$. In principle, such a shock could be microfounded by assuming a time-varying elasticity of substitution θ among intermediated goods. Equation (25) is instead a generalized Taylor rule that exhibits a certain degree of inertia and is defined in

[9] In our small-scale DSGE model the steady-state values for the main variables are given by: $w = (\theta-1)/\theta$, $C = 1/[w^{-1}(1-\gamma)]$, $Y = H = C$ and $1 + i = \Pi^*/\beta$. Notice that because of the full price indexation, steady-state inflation Π^* does not affect any of the real variables of the model but only the nominal interest rate.

terms of an inflation gap (expressed in deviation from a time-varying inflation target) and an output gap (expressed in deviation from the steady-state level of output). Finally, equations (26)-(28) describe the law of motion of the three exogenous processes that enter the model, namely the demand shock, the cost-push shock and the time-varying inflation target. As reported, each of these shocks is modelled as an AR(1) process.

The model contains two *jump* variables ($\hat{\pi}_t$ and $\hat{y}_t$), three *endogenous state* variables ($\hat{\pi}_{t-1}$, $\hat{y}_{t-1}$and $\hat{\imath}_t$) and three *exogenous state* variables (d_t, $\hat{s}_t$ and $\hat{\pi}_t^*$). In the next section we discuss how we introduce imperfect information regarding the state of the economy and what are the main implications.

3. Imperfect information and the signal-extraction problem

In this section we formalise 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 and the jump 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. Let us also assume that the central bank reacts to $\hat{\pi}_{t|t}$, $\hat{\pi}_{t|t}^*$ and $\hat{y}_{t|t}$.[10] In this case, the nominal interest rate rule can be written as

$$\hat{\imath}_t = \mathbf{F_1} X_{t|t} + \mathbf{F_2} x_{t|t} \tag{29}$$

where vectors $\mathbf{F_1}$ and $\mathbf{F_2}$ contain the policy coefficients. Hence, substituting (29) into (23) it is possible to cast the equations (23)-(28) in the following matrix format:

$$\begin{bmatrix} X_{t+1} \\ x_{t+1|t} \end{bmatrix} = \begin{bmatrix} \mathbf{A}_{11}^1 & \mathbf{A}_{12}^1 \\ \mathbf{A}_{21}^1 & \mathbf{A}_{22}^1 \end{bmatrix} \begin{bmatrix} X_t \\ x_t \end{bmatrix} + \begin{bmatrix} \mathbf{A}_{11}^2 & \mathbf{A}_{12}^2 \\ \mathbf{A}_{21}^2 & \mathbf{A}_{22}^2 \end{bmatrix} \begin{bmatrix} X_{t|t} \\ x_{t|t} \end{bmatrix} + \mathbf{B} \begin{bmatrix} \varepsilon_{t+1} \\ 0 \end{bmatrix}, \tag{30}$$

where $\mathbf{A}_{ij}^1$, $\mathbf{A}_{ij}^{12}$ 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 representation is convenient as it allows considering the case of perfect information by simply imposing that $X_{t|t} = X_t$ and $x_{t|t} = x_t$.

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

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[10] As for why the central bank does not know the inflation target see the discussion in the next section.

$$Z_t = [\mathbf{D}_1^1 \quad \mathbf{D}_2^1] \begin{bmatrix} X_t \\ x_t \end{bmatrix} + \nu_t \tag{31}$$

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

Under imperfect information agents estimate the state of the economy X_t observing the set of indicator variables Z_t and consistently with the model equations (23)-(28). As originally emphasised by Pearlman et al. (1986), the assumption of imperfect information poses rather complex issues 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:

$$x_{t|t} = \mathbf{G}^* X_{t|t} \tag{32}$$

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

$$\mathbf{G} = (\mathbf{GA_{12}} - \mathbf{A_{22}})^{-\mathbf{1}}(\mathbf{A_{21}} - \mathbf{GA_{11}}), \tag{33}$$

provided that $\mathbf{GA_{12}} - \mathbf{A_{22}}$ is invertible.[11] 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 holds).

Exploiting the result (32), it is possible to cast the model in terms of only predetermined variables. Such a representation is convenient because it allows using the Kalman filter to estimate the state of the economy based on the observable variables. After some algebra, the model dynamics can be expressed as:

$$X_{t+1} = \mathbf{H}X_t + \mathbf{J}X_{t|t} + \mathbf{B}\varepsilon_{t+1} \tag{35}$$

$$X_{t|t} = X_{t|t-1} + \mathbf{K}\left(Z_t - Z_{t|t-1}\right) \tag{36}$$

$$Z_t = \mathbf{L}X_t + \mathbf{M}X_{t|t} + \upsilon_t \tag{37}$$

where

$$\mathbf{H} = \mathbf{A_{11}^1} - \mathbf{A_{12}^1}\left(\mathbf{A_{22}^1}\right)^{-1}\mathbf{A_{21}^1} \tag{38}$$

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

$$\mathbf{J} = \mathbf{A}_{12}^{1}\left[\left(\mathbf{A}_{22}^{1}\right)^{-1}\mathbf{A}_{21}^{1} + \mathbf{G}^{*}\right] + \mathbf{A}_{11}^{2} + \mathbf{A}_{12}^{2}\mathbf{G}^{*} \tag{39}$$

$$\mathbf{L} = \mathbf{D}_{1}^{1} - \mathbf{D}_{2}^{1}\left(\mathbf{A}_{22}^{1}\right)^{-1}\mathbf{A}_{21}^{1} \tag{40}$$

$$\mathbf{M} = \mathbf{D}_{2}^{1}\left[\left(\mathbf{A}_{22}^{1}\right)^{-1}\mathbf{A}_{21}^{1} + \mathbf{G}^{*}\right] \tag{41}$$

$$\mathbf{K} = \mathbf{PL}'(\mathbf{LPL}' + \mathbf{\Sigma}_{v}^{2})^{-1}. \tag{42}$$

Equation (35) gives the law of motion of the state variables. Equation (36) 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.[12] The estimate of the state of the economy depends both on the covariance matrix of the structural innovations $\mathbf{\Sigma}_{\varepsilon}^{2}$ and of the measurement error $\mathbf{\Sigma}_{v}^{2}$.

Finally, equation (37) 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:

$$X_{t+1} = [\mathbf{H} + \mathbf{J}]X_t + \mathbf{B}\varepsilon_{t+1} \tag{43}$$

$$Z_t = [\mathbf{L} + \mathbf{M}]X_t + v_t \tag{44}$$

where $[\mathbf{H} + \mathbf{J}]$ and $[\mathbf{L} + \mathbf{M}]$ 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 acts as an inertial mechanism. This result has been emphasised 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. Indeed, 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 fit of a small-scale New Keynesian model.

Finally, note that the nominal interest rate rule can also be written as

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[12] The matrix P is the covariance matrix of the prediction errors; see Svensson and Woodford (2003).

$$\hat{\imath}_t = (\mathbf{F}_1 + \mathbf{F}_2\mathbf{G}^*)X_{t|t-1} + (\mathbf{F}_1 + \mathbf{F}_2\mathbf{G}^*)\mathbf{K}(Z_t - Z_{t|t-1}) \tag{45}$$

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, which generate unnecessary fluctuations in the economy.

4. Calibration

In this Section we discuss the calibration of the model. Most of the parameters are set on the basis of Ireland (2007). The calibration of the parameters is reported in Table 1. For the purpose of our analysis, the key parameters that need to be chosen are the degree of indexation of prices to the inflation target, the persistence of the stochastic process for the inflation target and the standard deviation of the measurement errors of the observable variables. Regarding the degree of indexation we fix it to 0.5 in the baseline simulations and then vary it between 0 and 1.

As for the stochastic processes of the shocks, we set the persistence of the preference and cost-push shocks at the posterior median (respectively, 0.77 and 0.56) estimated by Neri and Ropele (2011). The standard deviations of the innovations are also based on Neri and Ropele (2011): the volatility of the cost-push and preference shocks at, respectively, 0.059 and 0.064 percentage points. As for the inflation target, we set the AR(1) coefficient at 0.9 and the standard deviation of the innovations at 0.0081 percentage points; these figures are based on the average estimates of AR(1) processes fitted to the SPF long-run inflation expectations for the US and for the euro area.

The standard deviation of the measurement error attached to the inflation target is set at 0.25, based on the figure estimated for the U.S discussed in the Introduction. Regarding the standard deviation of the measurement error on inflation, we set it to a very small value, 0.03 percentage points (see Coenen, Levin and Wieland, 2005), in line with the limited revisions that characterize inflation. As for output we set the standard deviation of the associated measurement error to 0.8 percentage points (building again on Coenen, Levin and Wieland, 2005).

5. Results

In this section we discuss the dynamic effects of the structural shocks on the main variables of our small-scale DSGE model both under perfect information and imperfect information. In particular we are interested in the effects of shocks that bring about a persistent decline in inflation, and thus inspect the effect of a negative preference shock, a negative cost-push shock and a negative inflation target shock.

5.1 The effects of shocks under perfect information

To begin with we first assume perfect information, meaning that the state of the economy is fully observed by the agents in the economy, including the central bank. Figure 3 illustrates the impulse responses for each of the three structural shocks in the model.

In the first two columns are depicted the effects of a negative preference shock and of a negative cost-push shock. Under perfect information the resulting dynamic adjustments of these two shocks are fairly standard. A negative preference shock acts as a negative aggregate demand shocks that reduces output and brings inflation down. The central bank reacts by cutting the nominal interest rate and by so doing decreases the ex-ante real interest rate.[13] The expansionary monetary policy leads to a recovery in output that slowly returns to the steady-state level. Likewise, inflation gradually reverses back to the steady state.

The dynamic adjustment in response to a negative cost-push shock is different. The negative cost-push shock drives inflation below steady state. Also in this case the central bank reacts by cutting the nominal interest rate. The fall in the ex-ante real interest rate then stimulates consumption and output increases. The rise in output raises inflation, which eventually returns back to steady state. The cost-push shock hence moves output and inflation in opposite directions and temporarily modifies the trade-off facing the central bank between closing the inflation and output gaps.

In the last column of Figure 3 we report the impulse response functions to a negative shock to the inflation target. As discussed in Section 2 the central bank's inflation target enters two equations of the model: the monetary policy rule and the NKPC. On the one hand, a decline in the inflation target opens up a positive inflation gap and this will then call for an increase in the policy rate. On the other hand, a decline in the inflation target directly and negatively affects inflation through the indexation of prices and this – *ceteris*

[13] Studying the effects of the zero lower bound (ZLB) on nominal interest rate on the stabilization role of the monetary policy is beyond the scope of this paper. However, in Section 5.4 we will examine the effects of structural shocks when the central bank "cannot" respond by adjusting the policy rate. Recent research explores the effects of negative inflation shocks at the ZLB. Wieland (2014) empirically tests the prediction that negative oil supply shocks are contractionary at the ZLB.

paribus – will require an expansionary monetary policy. Hence, the effect of a decrease in the inflation target on the nominal interest rate will depend on the parameters calibration and in particular on the persistence of the shock and on the parameter $(1-\alpha)$ that governs the degree of indexation to the inflation target. In particular, the more persistent the inflation target shock and the smaller the values of α the more expansionary the monetary policy stance.

Given our benchmark calibration reported in Table 1, it turns out that in the event of a negative and persistent inflation target shock the central bank reacts by cutting the nominal interest rate and implementing a long-lasting expansionary monetary policy. The cut of the nominal interest rate is smaller than the decline in expected inflation. This then leads to an increase in the ex-ante real interest rate and a decrease in output on impact. As the ex-ante real interest rate slowly returns to steady state the output gap gradually closes and so does the inflation gap.

5.2 The effects of shocks under imperfect information

Next we move to consider how the dynamic adjustments to shocks modify under the more realistic scenario of imperfect information. As discussed in Section 2, when agents in the model do not observe the true state of the economy they can only estimate what shock has actually occurred based on the reading of noisy indicators. In this case, the agents might then perceive the occurrence of a shock even though it did not actually happen.

Figures 4 and 5 show the impulse responses to respectively a negative preference shock and a negative cost-push shock, comparing in both cases the effects under imperfect information (solid black line) and perfect information (dashed black line).

As shown in Figure 4, in the case of a true negative preference shock (top left panel) and imperfect information, agents perceive that a combination of all the three shocks has occurred (top right panel). In particular, they estimate the occurrence of small but negative preference, inflation target and cost-push shocks. The order of magnitude of these shocks is very small compared to the true preference shock. For this reason, the overall dynamic adjustment of inflation and output is remarkably more muted compared to the perfect information case. For instance, the response of output is virtually unaffected under imperfect information throughout the entire simulation horizon whereas under perfect information output on impact falls by nearly 0.15 per cent. The path of inflation shows even more interesting results. Up to the first 4 quarters, the dynamic adjustment of inflation under imperfect information is smaller than under perfect information, while it becomes slightly larger thereafter. This difference could reflect the fact that the preference and inflation target shocks under imperfect information exhibits a larger persistence than the true shock.[14] The response of the central bank is different in the two information settings, being more aggressive under perfect information. As a consequence, the decline in the ex-ante real interest rate is noteworthy under perfect information, whereas it barely varies under the alternative information setting.

All in all, when agents have imperfect information on the central bank's inflation target the occurrence of a negative preference shock that decrease inflation might lead the agent to perceive that a small downward revision of the inflation target might have taken place. However, in terms of the dynamic adjustment of the economy as a whole, the effects to not appear to be particular large.

Let us now turn to discuss the case of a cost-push shock. As shown in Figure 5, under imperfect information the agents underestimate the relevance of the cost-push shock and perceive that a negative preference shock and a negative inflation target shock have hit the economy. Consequently, as illustrated in the middle and bottom panels of Figure 5, the dynamic adjustments under the two information settings differ considerably. Except for the very few initial periods, the decline in inflation under imperfect information is larger and more persistent. Even more striking is the response of output. Rather than observing an increase in output as under perfect information, the impossibility to observe the state of the economy yields to a contraction in output. The differences with respect to the perfect information setup is that agents perceive that negative preference and inflation target shocks have occurred (top right panel), while they estimate the cost-push shock to be much smaller than the true one. In the imperfect information case the central bank cuts the nominal interest rate by less and this gives rise to an increase in the ex-ante real interest rate, rather than to a decline as under perfect information.

[14] By a simple visual inspection of the top two plots of Figure 4 it turns out that the half-life of the true preference shock is about quarters whereas the half-life of the perceived preference and inflation target shocks is about twelve quarters.

5.3 The role of key parameters

As discussed in the previous sections there are three parameters that may be crucial for the results. The first is α, which governs to what extent prices are indexed to past inflation rather than to the central bank's inflation target. When $\alpha = 0$ prices are fully indexed to Π_t^* whereas when $\alpha = 1$ prices are fully indexed to Π_{t-1}. Clearly the effect of a shock to the inflation target (either its true realization or the perceived one) depends on the value of α. The other two key parameters are $\sigma_{\pi,\nu}^2$ and ρ_π. These parameters may affect the filtering problem the agents are confronted with in the model under imperfect information. Also the variance of the innovation to the inflation target shock plays an important role in the filtering problem. However, we decided not to inspect its contribution more in depth as we think that this parameter is not under the control of the central bank. Instead we believe that $\sigma_{\pi,\nu}^2$ and ρ_π might to some extent be under the control of the monetary authority. More transparency regarding the inflation target might entail a lower measurement error and a longer duration of monetary policy committee members might entail a more persistent inflation target (more stable preferences of monetary policy committee members).

Figure 6 reports the impulse responses to structural shocks under perfect information and imperfect information for various values of the parameter α, ranging from zero (black solid line) to one (red solid line) with a step increase of 0.2. Under perfect information, as α decreases, i.e., a progressively larger weight is given to the inflation target in the indexation rule, inflation reacts more to structural shocks and exhibits a lower persistent pattern. The hump-shaped response that arises for large values of α progressively disappears and the dynamic adjustment becomes monotonic. Qualitatively similar results hold for the nominal interest rate. In this case, particularly large effects are observable in the case of the inflation target shock. Turning to output, our results show that as α decreases the response of output becomes more muted and persistent in the case of the preference shock and the inflation target shock, whereas the opposite holds true in the case of a cost-push shock.

Turning to the imperfect information case, several results are noteworthy.

First, as α decreases the negative response of inflation to the structural shocks becomes progressively larger and more persistent. Comparing to the perfect information case for large values of α, i.e., when inflation is more backward-looking, the response to the shocks on impact in significantly smaller whereas it is of the same order of magnitude when $\alpha = 0$. In the case of a preference shock and a cost-push shock the adjustment under imperfect information is also more persistent.

Second, under imperfect information the response of output depends a lot on the type of structural shock. In the case of a preference shock the adjustment of output is virtually unaffected by the values of α. In the case of a cost-push shock the effects are instead more significant. When $\alpha = 1$ there is an output increase on impact whereas for smaller values of α economic activity initially falls. When $\alpha = 0$ a hump-shaped and long-lasting recession occurs. In the case of an inflation target shock the effect of lowering α appears instead to mitigate the initial drop in output, although the dynamic adjustment becomes more persistent.

Third, for all three types of shocks, as α takes on lower values the central bank becomes progressively more aggressive and implements a long-lasting expansionary monetary policy.

Figure 7 shows the effects of varying the uncertainty surrounding the inflation target, which we achieve by changing the standard deviation of the measurement error of the inflation target. In our experiments we let the parameter $\sigma_{\pi,\nu}$ take on the following values: 0.001, 0.002, 0.003, 0.004, 0.005 and 0.006. As depicted in the figure, under perfect information changing the uncertainty of the measurement error of the inflation target does not play any role on the dynamic adjustment of the model.

Under imperfect information, instead, several important results stand out.

First, in response to either a preference shock or a cost-push shock the dynamic adjustment of inflation, output, nominal interest rate and ex-ante real interest rate amplify as the inflation target becomes more uncertain. This is particularly clear for inflation and the nominal interest rate. In the former case, as the parameter $\sigma_{\pi,\nu}$ rises the decline in inflation turns out to be more persistent. When $\sigma_{\pi,\nu} = 0.001$ inflation declines on impact and in the following period and then slowly reverts back to equilibrium. As $\sigma_{\pi,\nu}$ increases the length of deflation progressively increases as well. For example, when $\sigma_{\pi,\nu} = 0.006$ deflation lasts for about one year and only thereafter inflation reverts back to steady state. The paths for the nominal interest rate pretty much resemble those of inflation.

Second, while a higher inflation uncertainty magnifies of all other shocks, a positive shock to inflation uncertainty itself results in dampened affects. In this case, the larger the uncertainty the more the agents perceive that other shocks have hit the economy and thus the more muted the effects of the true inflation target.

Thus, our results show that as the uncertainty regarding the central bank's true inflation target the "non-monetary" structural shocks have a more destabilizing effect on the economy although the monetary authority implements a progressively more aggressive and expansionary monetary policy. The main driver of these results is the fact that the central bank fails to lower the ex-ante real interest rate in the first quarters after the shock so as to stimulate output. Thus, in this case the central bank should stand ready to react even more strongly.

Finally, Figure 8 illustrates the effects of varying the degree of persistence of the inflation target. In this case we let ρ_{π} take on five different values, namely: 0.8, 0.85, 0.9, 0.95 and 0.99. As depicted in the figure, in the case of perfect information changing the persistence of the inflation target only affects the transmission of the inflation target shock. Not surprisingly, as the persistence of the inflation target increases, the response of inflation to a negative inflation target shock becomes progressively more negative and more persistent and so does the nominal interest rate. The responses of output and the ex-ante real interest rate are virtually unaffected. Under imperfect information there are not major differences, except the fact that the responses on impact are in general significantly more muted.

As the other two structural shocks are concerned, our simulation results show that under imperfect information only when the persistence takes on very large values (in our case either 0.95 or 0.99) the effects are not negligible. These effects point in general to a smaller decline in inflation and in output. When $\rho_{\pi} = 0.99$, in response to a negative cost-push shock output does not fall on impact and expands thereafter for several quarters. Also the monetary policy becomes somewhat less aggressive.

5.4 Dynamic adjustment under zero-response monetary policy

In previous sections we have shown that, under imperfect information, when the uncertainty surrounding the central bank's inflation target increases (i.e. the parameter $\sigma_{\pi,\nu}$ rises) and prices become more indexed to the inflation target (the parameter α declines) the monetary authority reacts to "non-monetary" disinflationary shocks by implementing more and more aggressive expansionary monetary policies. It is then instructive to see what would happen to the dynamic adjustment of variables if the central bank were not able to manoeuvre its policy rate. This for example might arise if the economy was stuck at the zero lower bound (ZLB) and there was practically no room for further monetary policy easing via interest rate.

It is clearly beyond the scope of this paper to assess the interaction between the ZLB and inflation target uncertainty under imperfect information and thus we simply assume that for some unspecified reason the central bank keeps the nominal interest rate *virtually* unchanged. In practice, we achieve this results – without violating the Taylor principle – by assuming a very inertial interest rate rule and setting $\phi_i = 0.99999$. In this way the central bank finds very costly to deviate from yesterday's interest rate and therefore virtually does not respond to current economic conditions, namely the inflation and output gaps.

As illustrated in Figure 9, when the central bank is forced to follow a zero-response monetary policy the dynamic effects of shocks are visibly amplified in the short-run and more in general the adjustment paths are more volatile. For instance, under the zero-response monetary policy inflation – regardless of the shock hitting the economy – falls more in the short-run compared to the benchmark case and then returns more quickly to the steady state. In the case of a cost-push shock, inflation overshoots the steady-state inflation target after about 6 quarters and gradually reverts back to it thereafter. Larger short-run effects are also visible for the response of output, particularly in the case of a cost-push shock and the inflation target shock. Finally, and not surprisingly given that the nominal interest rate is basically kept unchanged, the adjustment paths of the ex-ante real interest rate mirror those of inflation and explain the responses of output.

Figure 10, instead, shows the interaction between the zero-response monetary policy and the uncertainty surrounding the central bank's inflation target. The idea here is to examine whether inflation target uncertainty might have non-linear effects on the impulse responses when the central bank cannot react to shocks. As shown in Figure 10 it turns out that when the central bank cannot react to current economic conditions and the uncertainty about the inflation target increases the occurrence of shocks have significant destabilizing effects on output and on the ex-ante real interest rate compared to the benchmark case where the central bank may operate its interest rate rule.

6. Robustness analysis

The slope of the Phillips curve is an important parameter in the mind of the monetary authority as it shapes the output-inflation trade-off. As discussed in Bean (2006) and Mishkin (2007b), a flattening of the Phillips curve has the benefit that higher levels of the output gap and lower levels of unemployment would be less inflationary. The problem of course would be that inflation, once established, would be harder to bring down. The reverse argument would hold in the case of a steepening of the Phillips curve.

Existing empirical studies have shown that the Phillips curve might be subject to some structural instability. Several authors have hinted at a 'flattening' of the Phillips curve during the Great Moderation, indicating that inflation has become less responsive to movements in measures of aggregate economic activity[15]. Other authors during the sovereign debt crisis have instead documented a steepening of the Phillips curve in the euro-area. For example, Venditti and Riggi (2015) recall that between 2013 and 2014, following the recession triggered by the sovereign debt crisis, euro-area inflation decreased sharply and more than expected by professional forecasters. As a possible explanation for this forecast failure they show that the sensitivity of inflation to the output gap may have recently increased, due to either lower nominal rigidities (a decrease in the average duration of prices) or to weaker strategic complementarities in price-setting, due to a reduction in the number of firms in the economy.

In this section we then analyse the robustness of our previous results to changes in slope of the NKPC. As shown in equation (24) the slope of the NKPC is given by the coefficient $\frac{1}{\phi}\left(\frac{\theta-1}{1-\gamma}\right)$ and depends on three structural parameters: the quadratic adjustment cost (ϕ), the elasticity of substitutions between differentiated inputs (θ) and finally the degree of external habit in consumption (γ). However, in our robustness analysis we focus just on the parameters ϕ and γ. The reason for doing so is twofold. First, in the log-linearized version of the model the parameters θ and ϕ only enter the slope of the NKPC; therefore, the results would be indifferent to changing either one or the other; we decided not to consider θ because the range of variation for this parameter in many existing studies is not very large and thus this would result in changing too little the slope of the

[15] For example, Roberts (2006) and Williams (2006) document the flattening of the Phillips curve for the U.S., Iakova (2007) does so for the U.K. and De Veirman (2007) for Japan.

NKPC. Second, conducting a robustness exercise on the parameter γ has the advantages of taking into consideration also the effect that such parameter has on the IS curve. As already discussed, a large value of γ rises the slope of the NKPC and at the same time makes the IS curve more backward-looking.

In particular, with regards to the parameter γ we consider two values, i.e., $\gamma = 0$ and $\gamma = 0.75$. In the first case the IS curve becomes completely forward-looking and the slope of the NKPC goes from 0.44 to 0.33. In the second case the degree of backward-lookingness of the IS curve increases and so does the slope of the NKPC, rising substantially from 0.44 to 1.33. As shown in Figure 11 the results are remarkably robust for all of the shocks. Perhaps minor differences compared to the benchmark case are visible in the case of the negative preference shock. In particular, in this case setting the degree of external habit in consumption to zero considerably amplifies the amplitude of the dynamic adjustment of the main economic variables.

Finally, in Figure 12 we present the results of varying the quadratic adjustment cost, setting either $\phi = 10$ or $\phi = 100$. In the former case the slope of the NKPC increases from 0.44 to 1.33, whereas in the latter case the slope reduces to 0.133. As shown in the figure the results are qualitatively very robust.

7. Conclusions

In this paper we have used a small-scale new Keynesian DSGE model to study the effects of persistent disinflationary shocks when the agents do not observe the state of the economy and in particular are unaware of the central bank's true inflation target. Compared to the unrealistic case of perfect information, our results suggest that in response to a negative preference shock inflation decreases less on impact but then it continues falling for several quarters before returning back to steady state. After a negative cost-push shock not only the decline in inflation is amplified but output contracts, while it expands under perfect information. This latter result is due to the fact that the cut in the nominal interest rate by the central bank is not large enough to lower the ex-ante real interest rate.

Our results show that, as the uncertainty regarding the central bank's inflation target increases, persistent disinflationary shocks exert more destabilizing effects on inflation and output, even though the central bank implements a more aggressive reduction in the nominal interest rate. If the central bank cannot adjust the nominal interest rate – because, for instance, of the zero lower bound – persistent disinflationary shocks entail even more contractionary effects.

The main policy implication of our study is that central banks should ensure that their inflation target is perfectly understood by agents and when this is not the case, they should react swiftly to transitory shocks to inflation.

A natural extension of our research is to examine the normative implications of varying the uncertainty around the inflation target, which of course calls for studying the optimal monetary policy. We leave this for future research.

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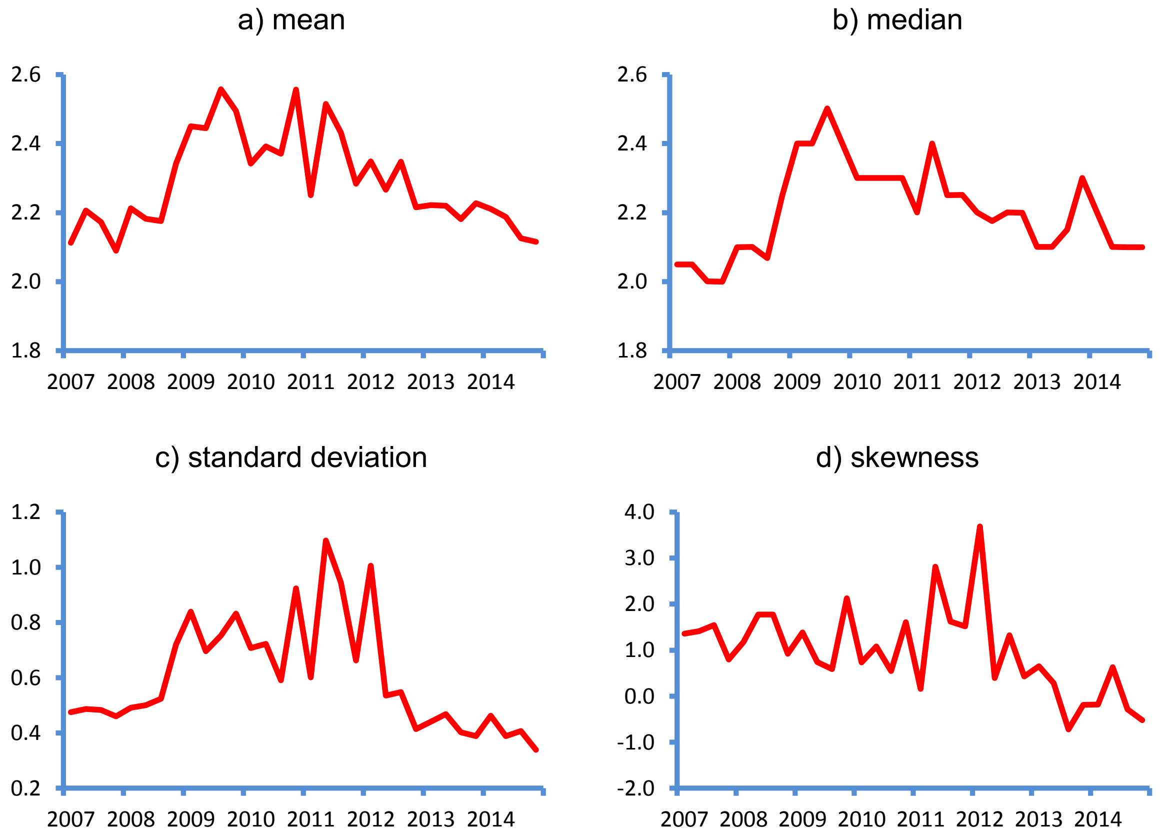
Tables and figures

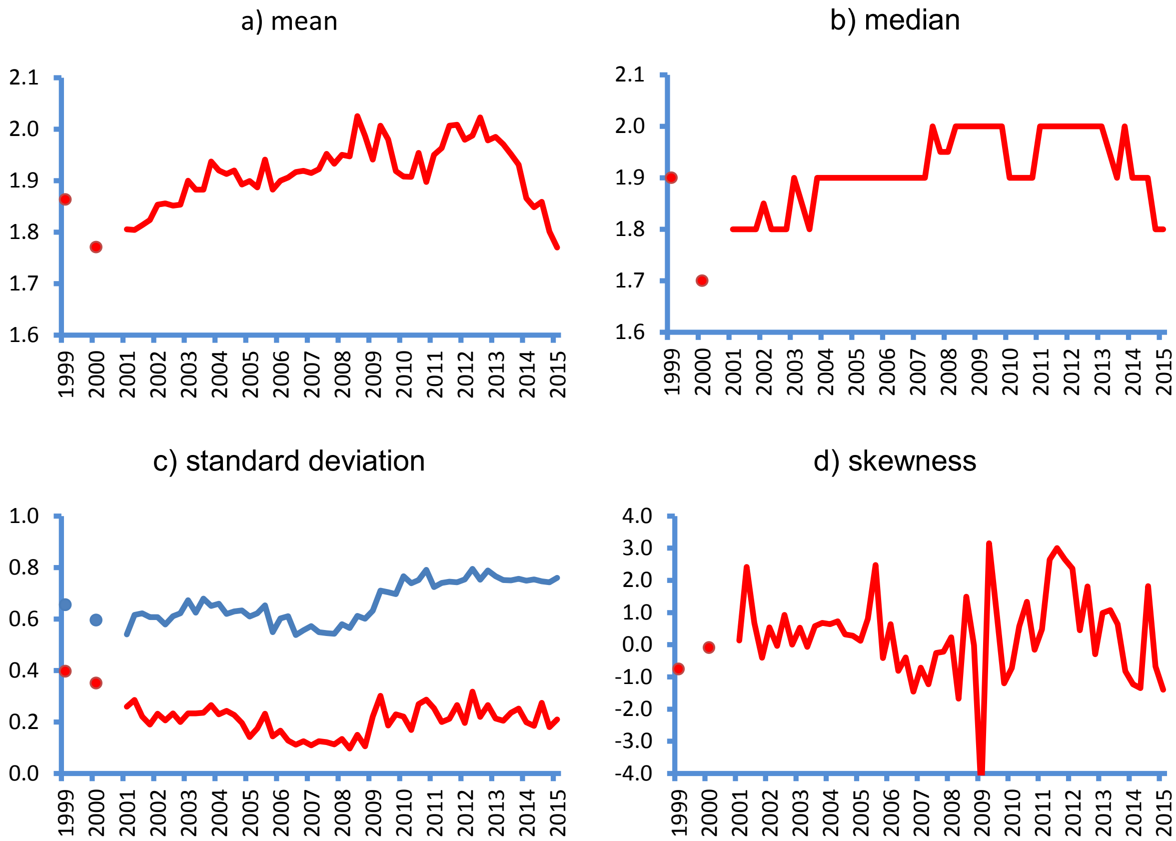
Figure 1. Descriptive statistics of long-term U.S. inflation expectations



Note: five-year inflation expectations five-year ahead for the personal consumption expenditure (PCE) deflator. Percentage points in annual terms.

Source: Federal Reserve Bank of Philadelphia. See http://www.philadelphiafed.org/research-and-data/real-time-center/survey-of-professional-forecasters/

Figure 2. Descriptive statistics of euro-area inflation expectations



Note: five-year expectations for the inflation rate based on the harmonized index of consumer prices (HICP). Percentage points in annual terms. Panel c) plots the standard deviation (red line) of individual expectations (disagreement) and the aggregate uncertainty (blue line), which is measured by the standard deviation of the aggregate probability distribution.

Source: European Central Bank. See http:/ http://www.ecb.europa.eu/stats/prices/indic/forecast/html/index.en.html

Figure 3. Impulse responses under perfect information

(*percentage deviations from steady state*)

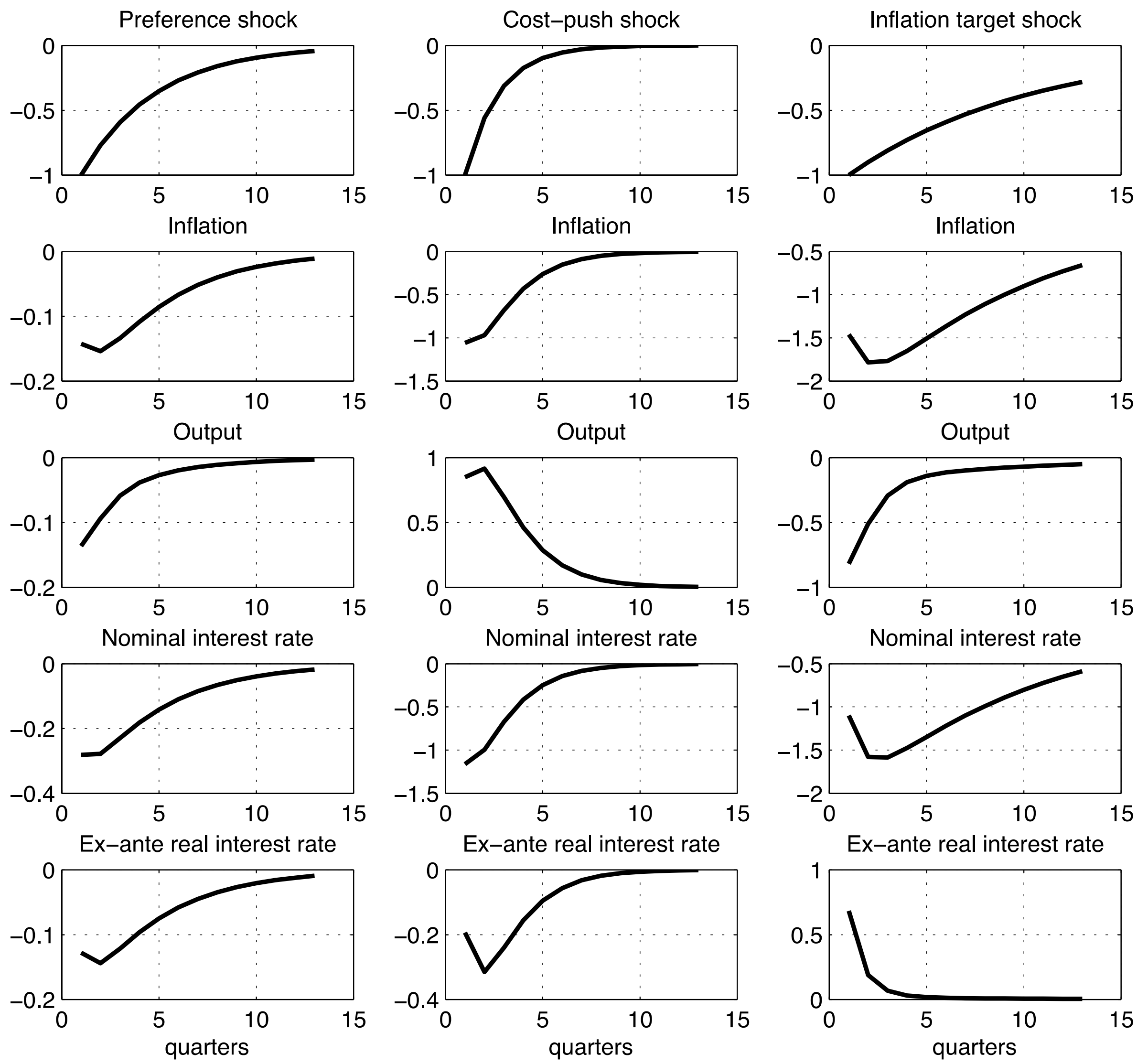


Figure 4. Impulse responses to a preference shock under imperfect information

(*percentage deviations from steady state*)

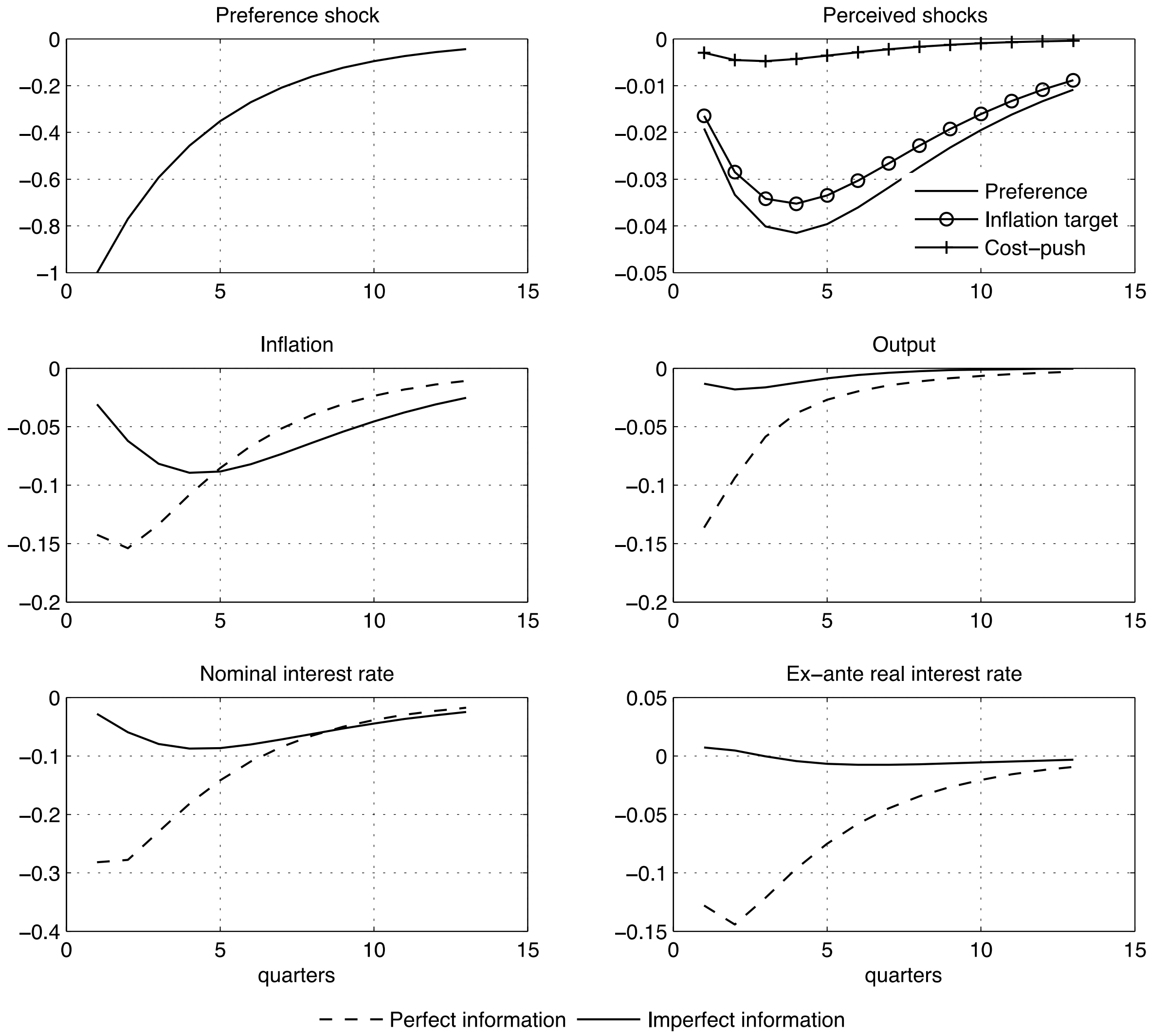


Figure 5. Impulse responses to a cost-push shock under imperfect information

(*percentage deviations from steady state*)

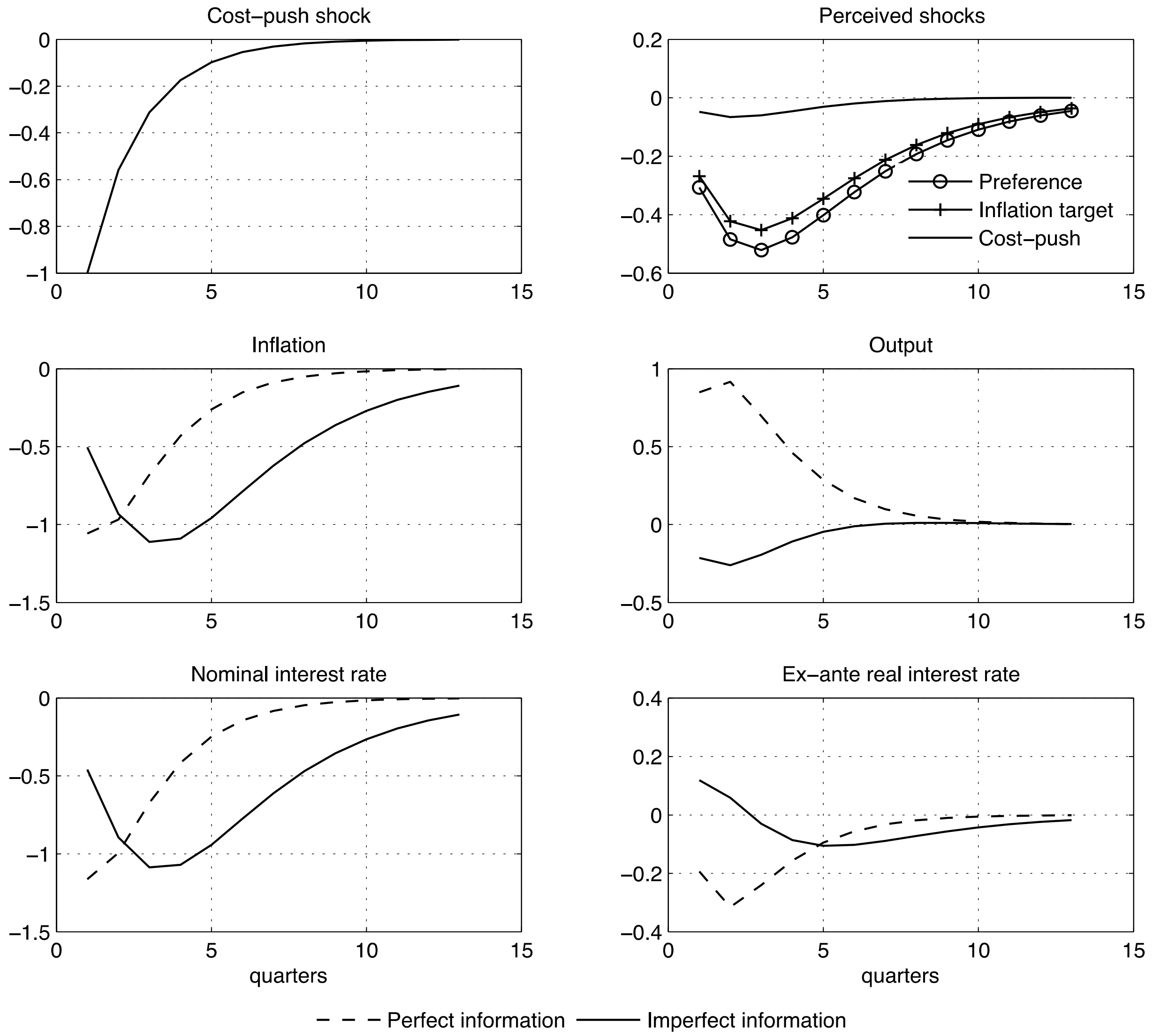


Figure 6. Impulse responses to a negative preference shock under perfect and imperfect information: varying the degree of price indexation to past inflation

(*percentage deviations from steady state*)

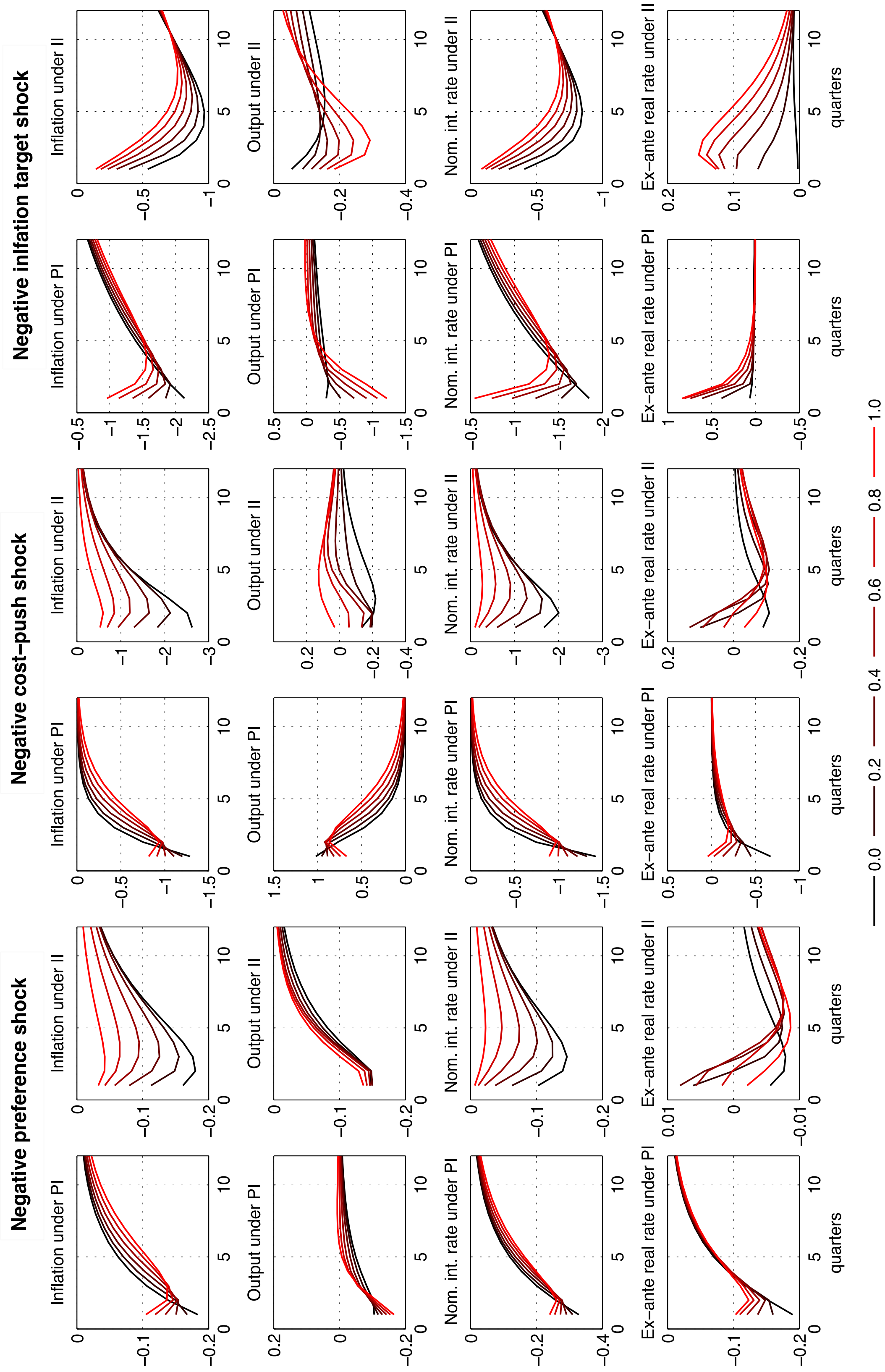


Figure 7. Impulse responses to structural shocks under perfect and imperfect information: varying the degree of uncertainty of the inflation target

(*percentage deviations from steady state*)

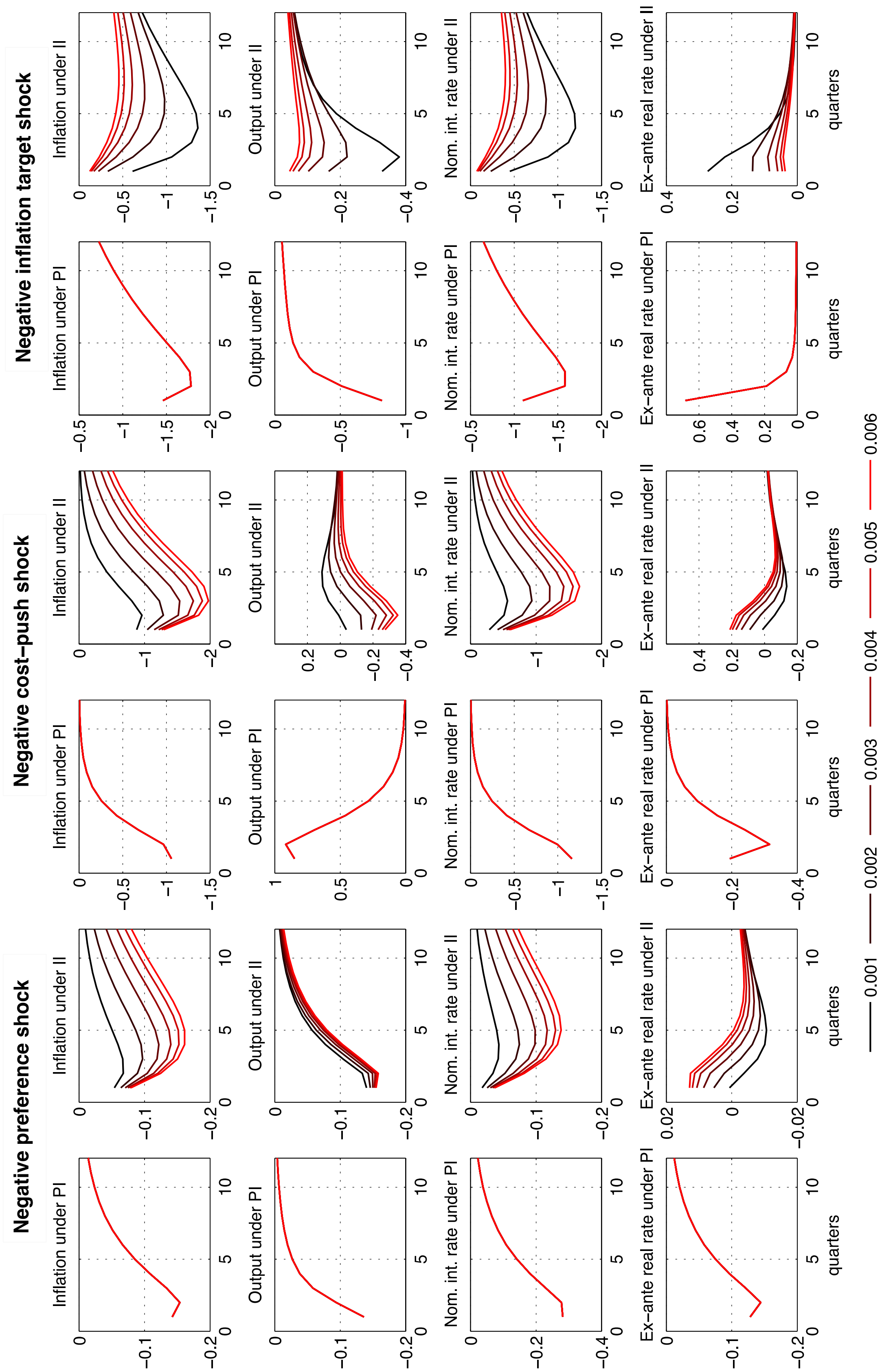


Figure 8. Impulse responses to structural shocks under perfect and imperfect information: varying the degree of inflation target persistence

(*percentage deviations from steady state*)

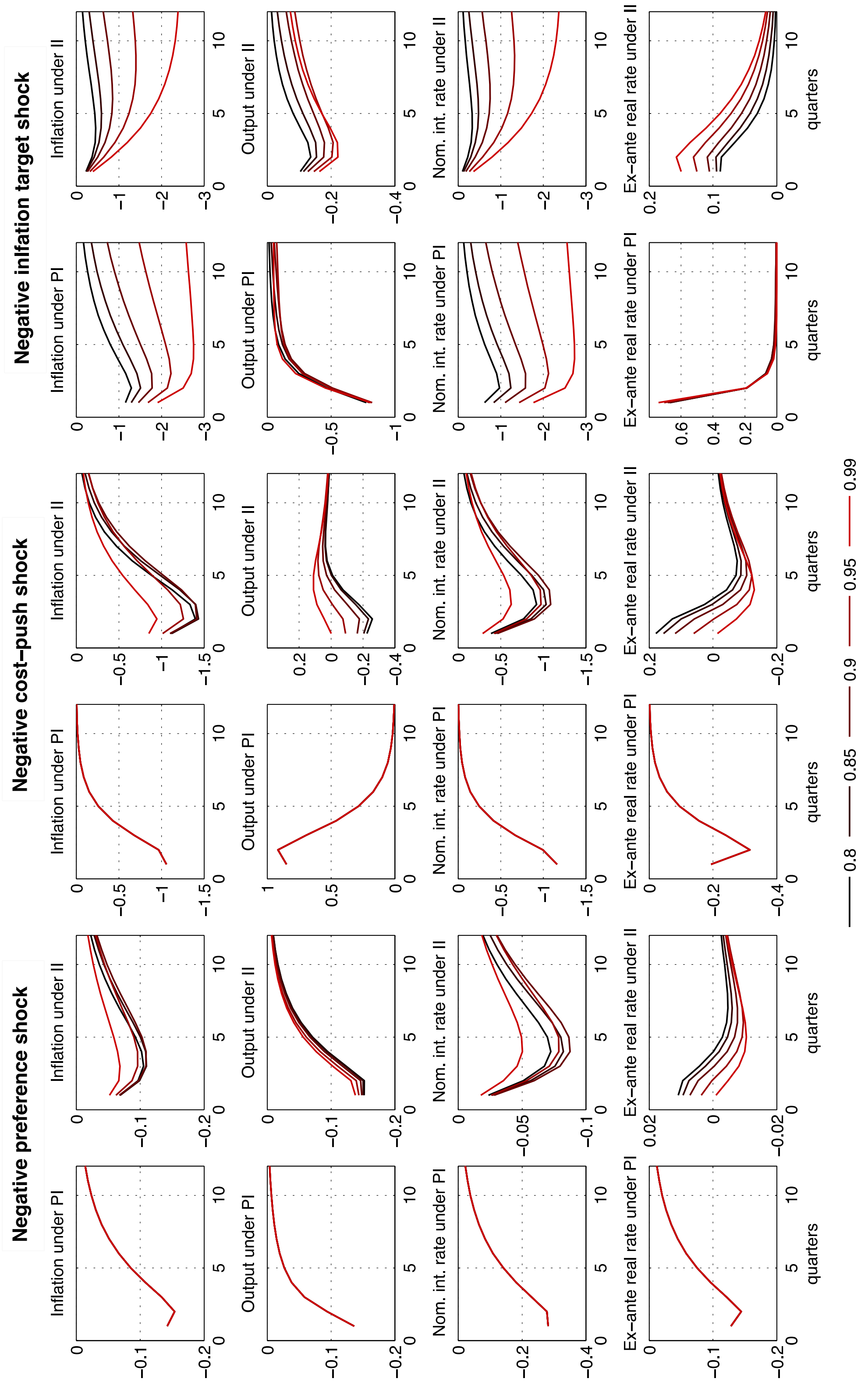
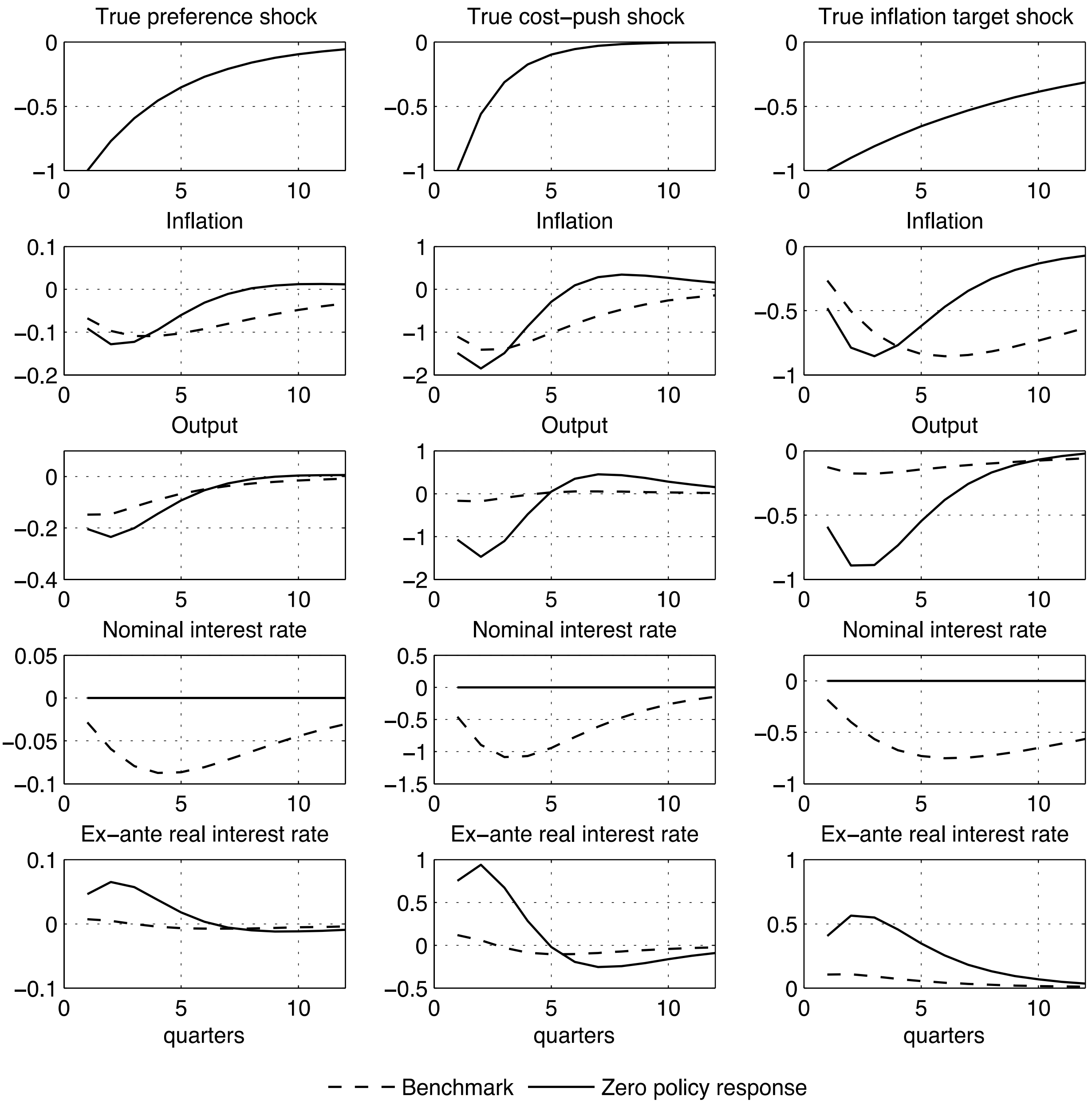


Figure 9. Impulse responses to structural shocks under imperfect information and zero policy response

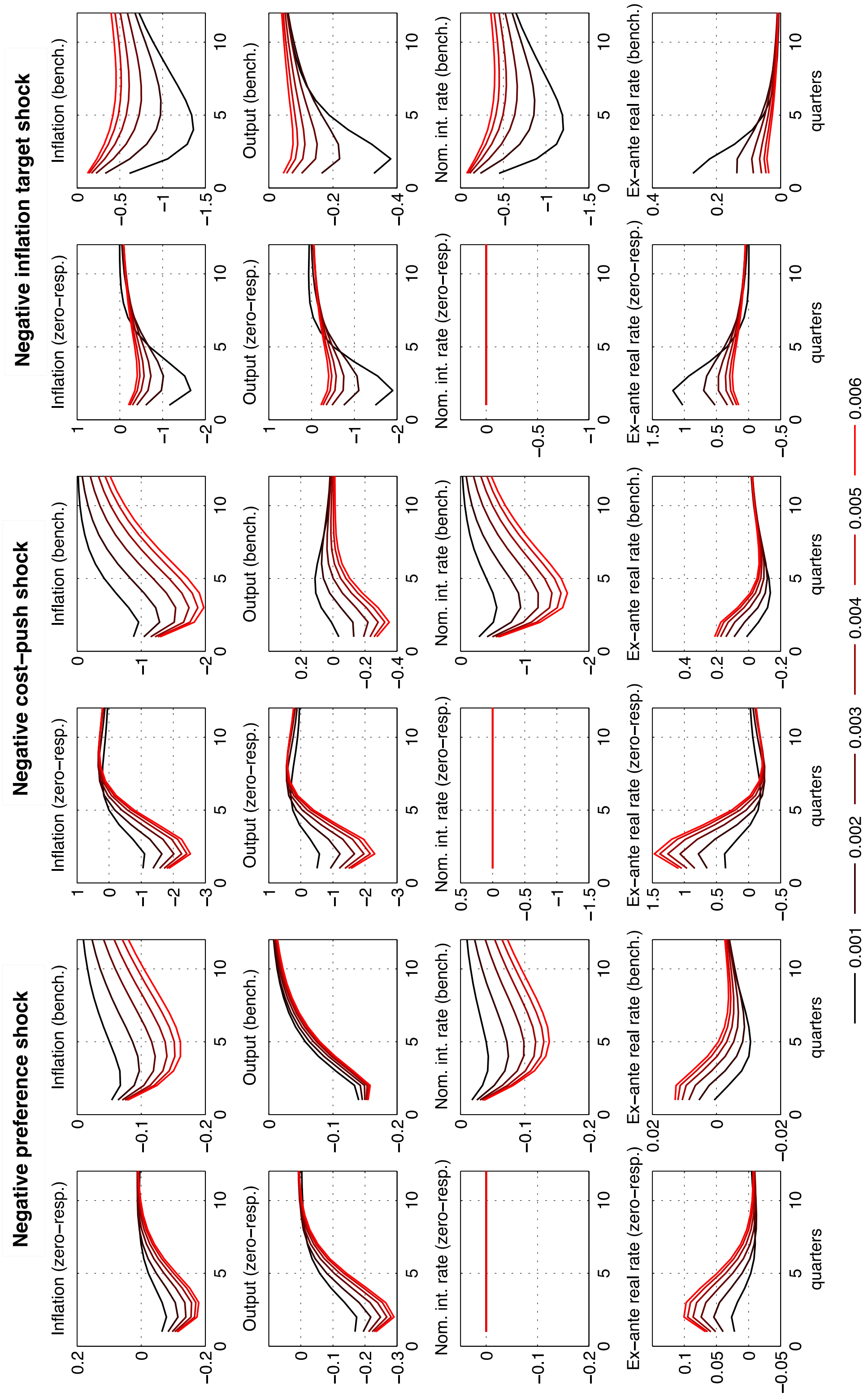
(*percentage deviations from steady state*)



Note: a no response of the nominal interest rate is obtained by setting $\phi_i = 0.99999$.

Figure 10. Impulse responses structural shocks under imperfect information: the effects of varying the degree of uncertainty on the inflation target in the benchmark monetary policy case and under the zero-response.

(*percentage deviations from steady state*)



Note: a no response of the nominal interest rate is obtained by setting $\phi_i = 0.99999$.

Figure 11. Robustness analysis: impulse responses to structural shocks when varying the degree of external habit persistence (i.e. the parameter γ).

(*percentage deviations from steady state*)

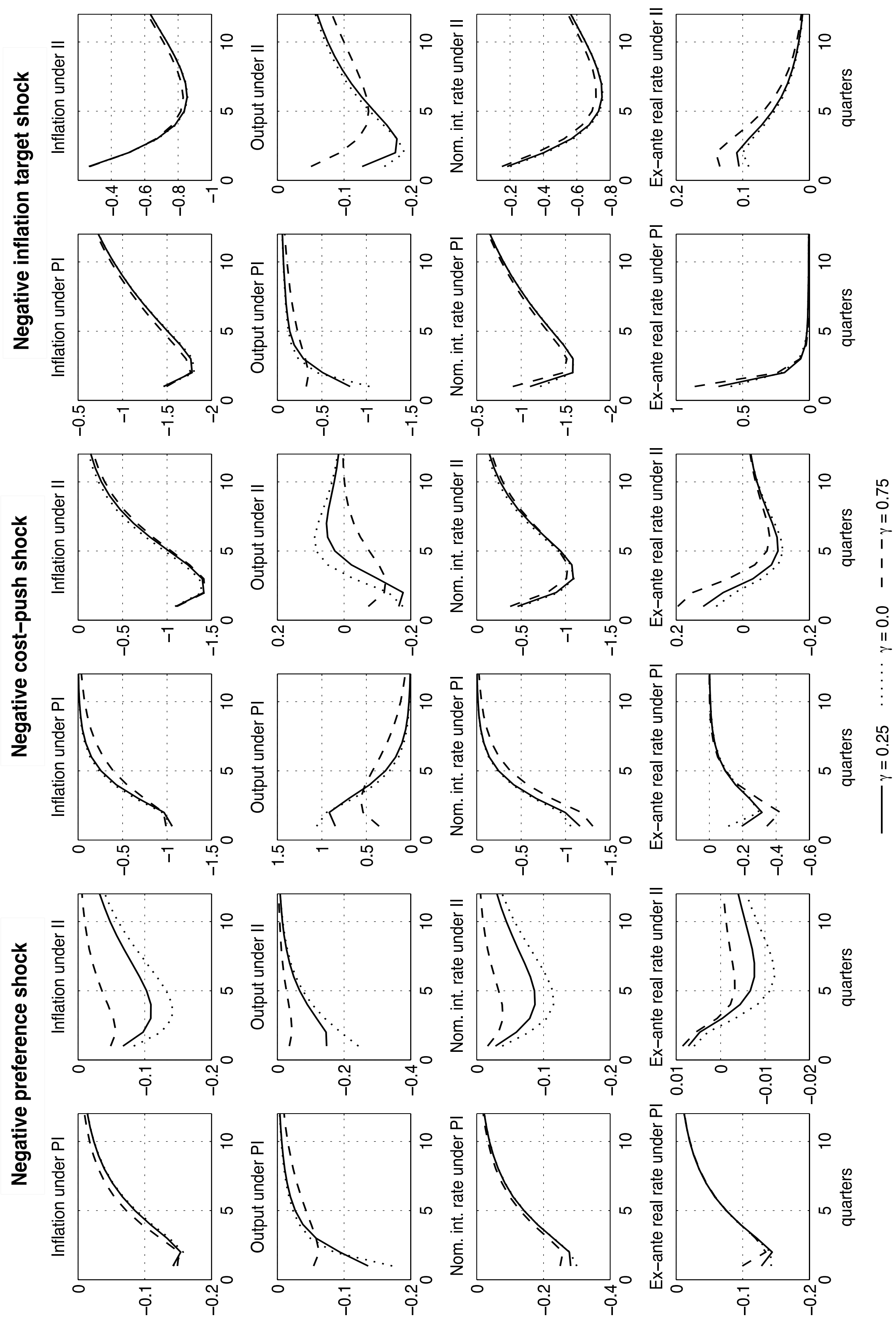


Figure 12. Robustness analysis: impulse responses to structural shocks when varying the quadratic adjustment cost (i.e. the parameter ϕ).

(*percentage deviations from steady state*)