Learning the monetary-fiscal interaction under trend inflation

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Abstract

How does a higher inflation target affect determinacy and learnability of rational expectations equilibria under alternative monetary/fiscal policy mixes in New Keynesian models? What is the role of central bank transparency? This paper proves that, in a non-Ricardian regime, determinacy and learnability conditions are insensitive to changes in trend inflation and to transparency issues: expectation stabilization requires taxes to react weakly to government debt. Conversely, a higher inflation target always destabilizes expectations under active monetary regimes. In a Ricardian regime, raising the inflation target requires a more hawkish central bank to attain determinacy. However, determinacy implies learnability only when agents are aware of both the inflation target and the central bank reaction function. If agents need to learn a positive inflation target, active monetary regimes are unstable. Therefore, fully disclosing the reaction function, including the target inflation rate, greatly increases the central bank's effectiveness in stabilizing expectations.

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1 Introduction

The bulk of the recent theoretical literature on monetary policy considers models where governments are ready to passively change taxes to cover public debt. Assuming an always satisfied government budget constraint is equivalent to leaving fiscal policy in the background. The Great Recession, with the joint stimulus of aggregate demand by both monetary and fiscal policies and the coordination problems among the two, has renewed attention on the 'fiscal theory of the price level', initiated by Sargent and Wallace (1981), Sims (1994), Leeper (1991), and Woodford (1996). This literature brings fiscal policy on the foreground together with monetary policy since it finds that the determination of the price level cannot abstract from their interactions.[1] In particular, the price level can be pinned down under rational expectations only in two different cases. In the first, the central bank implements a policy that complies with the Taylor principle while the government simply limits itself to satisfy its budget constraint - this situation has been dubbed as the active-monetary/passive-fiscal (AM/PF) case by Leeper (1991) or as the Ricardian case by Woodford (1996). In the second case, the government independently decides the level of the budget surplus (or deficit) while the central bank is required to adjust monetary policy in order to satisfy the government budget constraint through price level changes - the so-called passive-monetary/active-fiscal (PM/AF) or non-Ricardian case. The most recent literature on the argument (see, e.g., Bianchi, 2012; Davig and Leeper, 2011) employs Markov switching models to account for regime shifts in policy rules that take place through the years in a given country: next to the conventional case where an active monetary rule is associated to a passive rule, estimates document periods of passive monetary and active fiscal rules but even of double active or double passive policies.

This paper examines how the equilibrium properties of a New Keynesian model with monetary-fiscal interactions are modified when trend inflation is accounted for. Studying whether and how a variation in the inflation target affects the equilibrium properties of the model is particularly important in light of the recent proposals (Rogoff, 2008; Blanchard *et al.*, 2010; Ball, 2013) to increase the inflation target in order to exit from the zero lower bound region where monetary policy is ineffective. What are the effects of a higher inflation target on the determinacy properties under alternative monetary/fiscal policy mixes in New Keynesian models? Would it be more difficult for the central bank to still retain a tight grasp of inflation expectations once the infla-

[1] For a review of the existing literature on this issue see Canzoneri *et al.* (2011).

tion target is raised? What role for central bank transparency? To provide an answer to these questions we study, beyond equilibria determinacy, even expectational stability (E-stability). In order to do so, we need to drop the assumption of rational expectation and let private agents form their forecasts according to a recursive learning rule *à la* Evans and Honkapohja (2001). The analysis is undertaken assuming both an opaque central bank that does not communicate its policy to private agents and a transparent one, in light of the work of Eusepi and Preston (2010). Unlike the most recent literature, we do not explicitly model regime changes but, rather, we set a best-case scenario with a fixed-coefficient environment: if agents result unable to learn under this static context they, *a fortiori*, will find it more difficult to learn with policy regime shifts.

The rest of the paper is organized as follows. After having devoted the next subsection to highlight similarities and differences from related literature, Section 2 presents the model and the methodology. Section 3 contains the determinacy results under zero (3.1) and positive trend inflation (3.2), the learning analysis (3.3) and the impulse response functions derived from the model (3.4). Section 4 provides some robustness checks and Section 5 concludes.

1.1 Related literature

This paper may be considered as an extension of Ascari and Florio (2012) to a setting with an explicit role for fiscal policy.[2] Beside studying determinacy and learning under opacity and transparency in a New Keynesian model with trend inflation, we also provide an analysis of the impulse response function of the model. This should be of interest from a double perspective. First, it shows if and how the transmission mechanism of economic shocks changes when alternative policy mixes are in place. Second, it reveals how high levels of trend inflation affect the results.

In order to better organize the exposition, we divide the related literature distinguishing among papers that deal, respectively, with determinacy, learning and impulse response analyses under monetary-fiscal interactions.

[2] In this section we will just report the literature dealing with monetary-fiscal interactions. We refer the interested reader to Ascari and Florio (2012) for a more general review of the literature on learning and trend inflation.

1.1.1 Determinacy

The pivotal paper studying determinacy under both active and passive monetary and fiscal rules is Leeper (1991). The author, employing a flexible price model with contemporaneous policy rules and lump-sum taxes, shows that there is a unique stable equilibrium (determinacy) only if the fiscal and monetary authorities coordinate their policies (AM/PF or PM/AF). On the other hand, a lack of coordination returns multiple equilibria (indeterminacy) in case of a double passive mix or lack of equilibrium (explosiveness) with a double active mix. Branch *et al.* (2008) extend the paper by Leeper (1991) to include determinacy analysis for different monetary policy rules under the same (flexible price) model. A work closer to ours is instead represented by Rossi (2009), who studies the equilibrium determinacy of a New Keynesian model with trend inflation and public debt. However, Rossi does not account for non-rational expectations and employs distortionary taxation, while our study deals with learning and maintains Leeper's (1991) assumption of lump-sum taxes.

1.1.2 Learning

Evans and Honkapohja (2007) study the learning properties of Leeper's (1991) flexible price model by finding that determinate equilibria are also E-stable. Our analysis, as for learning is concerned, is an extension of theirs along three dimensions: we consider a model with price rigidity, we include trend inflation and we look at expectational stability under both monetary policy transparency and opacity. Apart from the inclusion of trend inflation, our model is close to Eusepi and Preston (2012) who study learning dynamics under uncertainty about monetary and fiscal conditions and find that, in this case, stabilization policies are more difficult than under rational expectations. To enlarge the set of policies consistent with E-stability, the expectations about monetary and fiscal policies should be anchored through transparency. Our paper abstracts from transparency considerations on fiscal policy though we consider it a fruitful point for future research.

Kobayashi and Muto (2013) and Kurozumi (2014) study determinacy and expectational stability of a New Keynesian model under trend inflation. Compared to these papers we offer two main contributions: (i) monetary/fiscal interactions and (ii) the effects of central bank's transparency on the anchoring of expectations. A further difference is the assumption about the learning process, namely the dating of expectations.[3]

1.1.3 Impulse response analysis

Following Kim (2003), Canzoneri *et al.* (2011) use impulse response functions to show the different effects of policy innovations according to the monetary/fiscal regime in place in a cash and credit goods model.[4] While in the Ricardian case shocks have the conventional effects, in the non-Ricardian case the presence of wealth effects modifies the impulse responses. By introducing trend inflation we can show that the impulse responses of our model change not only depending on the policy mix but also on the level of the inflation target.

2 Model and methodology

2.1 The Model

The model we use is based on Ascari and Ropele (2009), that extends the basic New Keynesian (NK) framework (e.g., Woodford, 2003; Galí, 2008) to allow for positive trend inflation. Fiscal policy is added following Bhattarai *et al.* (2014) by introducing a simple backward looking fiscal rule with lump-sum taxes and one-period government bonds. Details on the model are left in the online appendix. Log-linearizing the model around a generic positive inflation steady state yields the following equations:

$$\hat{y}_t = E^*_{t-1}\hat{y}_{t+1} - E^*_{t-1}\left(\hat{R}_t - \hat{\pi}_{t+1}\right), \tag{1}$$

$$\hat{\pi}_t = \beta\bar{\pi}E^*_{t-1}\hat{\pi}_{t+1} + \lambda_{\bar{\pi}}E^*_{t-1}\left[(1+\sigma_n)\,\hat{y}_t + \sigma_n\hat{s}_t\right] + \eta_{\bar{\pi}}E^*_{t-1}\left[(\theta-1)\,\hat{\pi}_{t+1} + \hat{\phi}_{t+1}\right], \tag{2}$$

$$\hat{\phi}_t = \alpha\beta\bar{\pi}^{(\theta-1)}E^*_{t-1}\left[(\theta-1)\,\hat{\pi}_{t+1} + \hat{\phi}_{t+1}\right], \tag{3}$$

$$\hat{s}_t = \xi_{\bar{\pi}}\hat{\pi}_t + \alpha\bar{\pi}^{\theta}\hat{s}_{t-1}, \tag{4}$$

$$\hat{R}_t = \phi_\pi E^*_{t-1}\hat{\pi}_t + \varepsilon_{m,t}, \tag{5}$$

$$\hat{\tau}_t = \gamma\hat{b}_{t-1} + \varepsilon_{\tau,t}, \tag{6}$$

$$\hat{b}_t = \beta^{-1}\hat{b}_{t-1} + \bar{b}\beta^{-1}(\hat{R}_{t-1} - \hat{\pi}_t) - \hat{\tau}_t. \tag{7}$$

[3] See Section 3.3.2 and the robustness checks in Section 3.5 for the implications of their dating of expectations on the results.

[4] Kim (2003) employs a money-in-utility model.

Hatted variables denote percentage deviations from steady state,[5] apart from $\hat{y}$, which is the usual New Keynesian output gap defined as deviation from the flexible price output level. The structural parameters and their convolutions ($\lambda_{\bar{\pi}}$, $\eta_{\bar{\pi}}$ and $\xi_{\bar{\pi}}$) are described in Table 1. $\varepsilon_{m,t}$ and $\varepsilon_{\tau,t}$ are the monetary and fiscal policy shocks that follow the autoregressive processes $\varepsilon_{m,t} = \rho_m \varepsilon_{m,t-1} + u_{m,t}$ and $\varepsilon_{\tau,t} = \rho_\tau \varepsilon_{\tau,t-1} + u_{\tau,t}$, where $u_{m,t}$ and $u_{\tau,t}$ are i.i.d. noises and $0 < \rho_m, \rho_\tau < 1$.

Equation (1) is the standard Euler equation for consumption. Equations (2) and (3) describe the evolution of the inflation rate in presence of trend inflation. $\hat{\phi}_t$ is just an auxiliary variable (equal to the present discounted value of future expected marginal revenue) that allows writing the model in recursive way. Equation (4) describes the evolution of price dispersion, $\hat{s}_t$. In contrast to the zero inflation steady state case, under positive trend inflation price dispersion affects inflation dynamics even at first-order approximation and thus has to be taken into account. Equations (2)-(4) are the counterparts of the New Keynesian Phillips curve for the standard zero inflation steady state case. Equation (5) is the simplest standard contemporaneous Taylor rule. Equation (6) is the fiscal policy rule that sets taxes according to outstanding real debt, while eq. (7) is the flow budget constraint of the government (where $\bar{b}$ is the steady state debt-over-GDP ratio). By plugging the fiscal rule into the budget constraint we obtain

$$\hat{b}_t = (\beta^{-1} - \gamma)\hat{b}_{t-1} + \bar{b}\beta^{-1}(\hat{R}_{t-1} - \hat{\pi}_t) - \varepsilon_{\tau,t}.$$

Following Evans and Honkapohja (2001) and much of the related literature on learning, we deviate from Ascari and Ropele (2009) and assume that agents have non-rational expectations, that we denote with E^*. Furthermore, we assume that expectations are formed using the information set available at period $t-1$ (as in Bullard and Mitra, 2002). According to Evans and Honkapohja (2001), this assumption is more natural in a learning context, since it avoids simultaneity between expectations and current values of endogenous variables.

2.2 Methodology

We are interested in analysing both determinacy and learnability conditions. As for determinacy, we refer the reader to Sections 3.1 and 3.2 where we discuss the determinacy conditions, respectively, under a zero inflation target and under positive trend inflation (for the case with

[5] We use the definitions $\hat{b}_t = \frac{b_t - b^*}{y^*}$ and $\hat{\tau}_t = \frac{\tau_t - \tau^*}{y^*}$, where we indicate the steady state values with a star.

Table 1. Parameters description and benchmark calibration

Parameter	Value	Description
β	0.99	Intertemporal discount factor
σ_n	1.00	Inverse intertemporal elasticity of substitution in labour supply
θ	11.00	Dixit-Stiglitz elasticity of substitution
α	0.75	Calvo probability not to optimize prices
$\bar{\pi}$		Central bank inflation target (or trend inflation)
ϕ_π		Inflation parameter in the Taylor rule
γ		Fiscal rule parameter
$\bar{b}$	0.40	Debt/GDP
ρ_m	0.90	Monetary shock persistence
ρ_τ	0.90	Fiscal shock persistence
NKPC coefficients definition		
$\lambda_{\bar{\pi}}$	$\left(1-\alpha\bar{\pi}^{\theta-1}\right)\left(1-\alpha\beta\bar{\pi}^{\theta}\right)\left(\alpha\bar{\pi}^{\theta-1}\right)^{-1}$	
$\eta_{\bar{\pi}}$	$\beta\left(\bar{\pi}-1\right)\left(1-\alpha\bar{\pi}^{\theta-1}\right)$	
$\xi_{\bar{\pi}}$	$\theta\alpha\bar{\pi}^{\theta-1}\left(\bar{\pi}-1\right)\left(1-\alpha\bar{\pi}^{\theta-1}\right)^{-1}$	

indivisible labour and no price indexation $\sigma_n = \varepsilon = 0$). In case of positive trend inflation, we provide additional numerical simulations to investigate the relevance of our analytical results. Section 3.3 deals, instead, with numerical simulations under learning.

2.2.1 Learnability

When agents do not possess rational expectations, the existence of a determinate equilibrium does not ensure that agents coordinate upon it. As in the seminal contribution of Evans and Honkapohja (2001), we assume that agents do not know the true structure of the economy. Rather, they behave as econometricians and learn adaptively, using a recursive least square algorithm based on the data produced by the economy itself. If the rational expectation equilibrium is learnable, the learning dynamics will tend toward, and eventually coincide with, the rational expectations equilibrium. Learnability is then an obviously desirable feature of monetary policy.

We apply E-stability results outlined in Evans and Honkapohja (2001, section 10.2.1). Agents are assumed to have identical beliefs and to forecast using variables that appear in the minimal state variable (MSV) solution of the system under rational expectations. The form of agents' perceived law of motion (PLM) coincides with the system MSV solution, up to a constant. As our model is written in deviations from the steady state, the MSV solution does not include a constant term. If we assume that agents know the inflation target set by the central bank, the PLM does not contain a constant, either. Conversely, when agents are required to learn the inflation target the PLM will be augmented with a constant. We consider both cases in the following discussion. Agents are assumed to know just the autocorrelation of the shocks but they have to estimate the remaining parameters. Each period, as additional data become available, they re-estimate the coefficients of their model. We then ask whether agents are able to learn the MSV equilibrium of the system (see the online appendix for details).

2.2.2 Transparency versus opacity

In defining opacity (OP) and transparency (TR) of monetary policy, we follow closely the work of Preston (2005) and Eusepi and Preston (2010). We assume that the central bank is perfectly credible: the public believes and fully incorporates central bank's announcements. Agents are uncertain about the economy ($\hat{\pi}$, $\hat{y}$ and $\hat{b}$) and about the path of nominal interest rates ($\hat{R}$). Communication by the central bank simplifies the agents' problem in that it gives them information on how the monetary authority sets interest rates, that is, on the monetary policy strategy. Therefore, under OP the private sector has to learn about the economy and about monetary policy; under TR, private agents need to forecast just the economy but not the path of nominal interest rates, since the central bank announces its reaction function. In case of TR, we incorporate the reaction function directly in the aggregate demand equation and the agents' problem boils down to forecasting inflation, output and debt. This, as we will show, should be of help in anchoring expectations by aligning agents' beliefs with the central bank's monetary policy strategy.

3 Results

This section presents the main results of the paper. We first consider the standard case of a zero inflation target (i.e., zero inflation steady state), for which we recall, in the context of our model, the analytical results available in literature. We then move to the more general and realistic case of a positive inflation target for which some analytical conditions and numerical simulations are provided.

We follow Leeper's (1991) definition of active/passive monetary and fiscal policy: a policy authority has an 'active' behaviour when it pursues its objective unconstrained by the actions of the other authority; instead, if the authority is constrained, its behaviour is 'passive'. Table 2 shows the possible policy mixes that can take place in our model for different values of the parameters in the policy functions. Note that active fiscal policy corresponds to two different areas depending on the value of γ, respectively $\gamma < (1/\beta - 1)$ (AF_{down} region) and $\gamma > (1/\beta + 1)$ (AF^{up} region). Previous studies concentrate only on the AF_{down} region, where the additional tax revenue generated by a small increase in the level of debt is less than the increase in interest rates payments. The other region is disregarded, as the values of γ appear non reasonable. For $\gamma > (1/\beta + 1)$, in fact, a shock raising debt would make taxes increase even beyond the amount required to pay off the debt (including interest rates). In what follows, as an intellectual curiosity, we show results even for this second area.

Table 2. Monetary/fiscal policy mixes for different values of ϕ_π and γ

	$0 < \phi_\pi < 1$	$\phi_\pi > 1$
$\gamma > 1/\beta + 1$	PM/AF^{up}	AM/AF^{up}
$1/\beta - 1 < \gamma < 1/\beta + 1$	PM/PF	AM/PF
$\gamma < 1/\beta - 1$	PM/AF_{down}	AM/AF_{down}

3.1 Determinacy under zero-inflation target

Consider eqs (2)-(4). After assuming zero trend inflation ($\bar{\pi} = 1$), one obtains $\eta_{\bar{\pi}} = \xi_{\bar{\pi}} = 0$, thus both the auxiliary variable and the measure of relative price dispersion become irrelevant for inflation dynamics and the three equations collapse into

$$\hat{\pi}_t = \beta E^*_{t-1}\hat{\pi}_{t+1} + \kappa E^*_{t-1}\hat{y}_t, \tag{8}$$

where $\kappa = \lambda(1 + \sigma_n)$. Therefore, the model reduces to a three-equation dynamic system in the variables $\hat{y}_t$, $\hat{\pi}_t$, and $\hat{b}_t$. The Blanchard-Kahn conditions for determinacy of the REE depend, beside the Taylor principle, on the fiscal policy implemented by the government. The determinacy properties of our model trace the original findings obtained by Leeper (1991) in his flexible price model: in case of passive fiscal policy, there is determinacy if monetary policy is active. Conversely, in case of active fiscal policy determinacy holds if monetary policy is passive (proofs can be found in the online appendix). Whereas the equilibrium is indeterminate under PM/PF and explosive under AM/AF.

3.2 Determinacy under positive trend inflation

We now study how a positive trend inflation modifies the determinacy regions. In order to compare our results with the existing literature, we discuss the flexible price and sticky price cases separately.

3.2.1 Flexible prices

Following the pivotal article by Leeper (1991) that adopts a representative agent, flexible price, endowment economy, we check what happens to determinacy when trend inflation rises in absence of price rigidity ($\alpha = 0$). Figure 1 illustrates the determinacy regions for different values of the parameters of the monetary (ϕ_π) and fiscal (γ) policy rules.[6] The white area indicates determinacy, the dark grey area instability, the light grey area explosiveness. It is important to note that the areas are identical to the zero inflation case and do not change as the inflation target increases. We can therefore conclude that:

Result 1. Under flexible prices trend inflation does not affect determinacy.

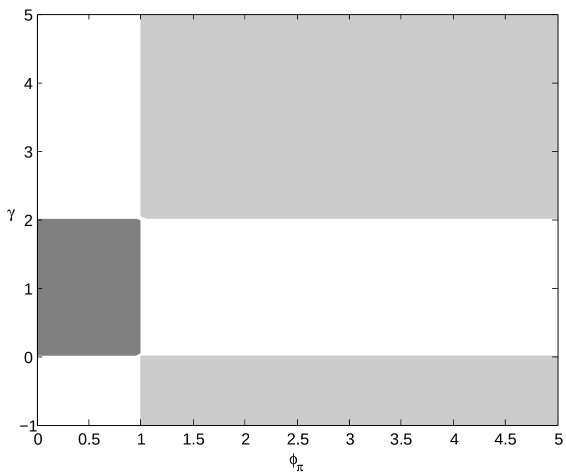

Fig. 1. Determinacy for every level of trend inflation under flexible prices
Notes: Indeterminacy: dark grey area; instability: light grey area; determinacy: white area.

Price flexibility completely offsets the effects of trend inflation. Price-setting firms have always the possibility to change their prices to compensate the erosion of relative prices and profits that trend inflation automatically creates.

[6]In the numerical simulation of the paper, unless otherwise stated, we use the rather standard parameter values reported in Table 1.

3.2.2 Sticky prices

We now return to our sticky price model with trend inflation. In order to get analytical conditions for determinacy, throughout this section we set $\sigma_n = 0$ (i.e. indivisible labour) and $\varepsilon = 0$ (no price indexation). Proofs can be found in the online appendix.

Proposition 1. Determinacy of the REE under positive trend inflation and passive fiscal policy obtains if and only if

$$\phi_\pi > \max(1, z(\bar{\pi})).$$

$z(\bar{\pi})$ above is the largest root of a second degree inequality for ϕ_π (eq. 17 in the online appendix). We adopt a numerical approach to compute the two roots of such equation for different values of $\bar{\pi}$: we find both roots to be real and of opposite sign, so we label the largest root $z(\bar{\pi})$. Therefore the binding condition for determinacy is $\phi_\pi > \max(1, z(\bar{\pi}))$.

The function $z(\bar{\pi})$ is shown in Fig. 2 and is computed by fixing all parameters other than $\bar{\pi}$ to their benchmark calibrated values. Importantly, our simulations show that $\partial z(\bar{\pi})/\partial\bar{\pi} > 0$ and that $z(\bar{\pi}) > 1$ when annualized trend inflation increases above 2.3%.

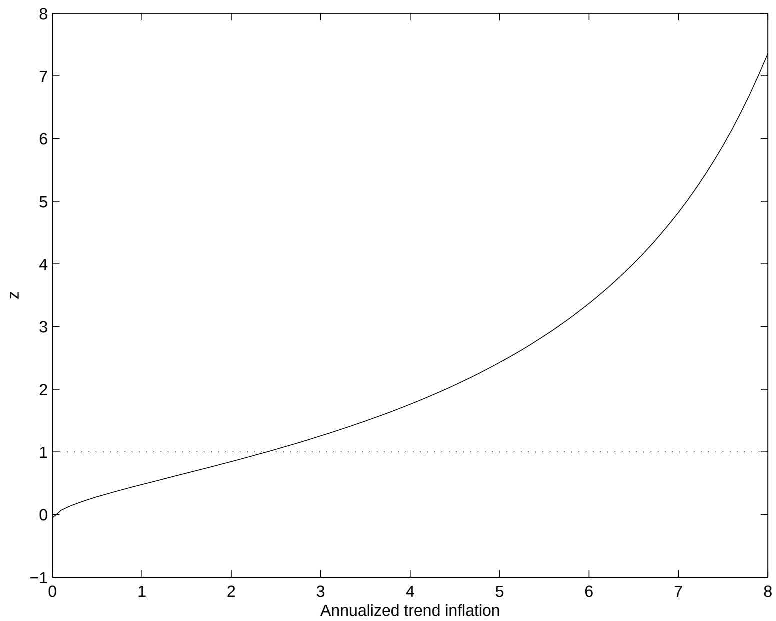

Fig. 2. Function $z(\bar{\pi})$ for every level of trend inflation

Proposition 2. Under active fiscal policy, determinacy is obtained if and only if

$$\phi_\pi < 1.$$

To investigate the relevance of these analytical results we revert to numerical simulations. Figure 3 illustrates the determinacy region in the plane (ϕ_π, γ) for different levels of annualized trend inflation under a contemporaneous rule with $\alpha = 0.75$ and $\sigma_n = 1$.[7]

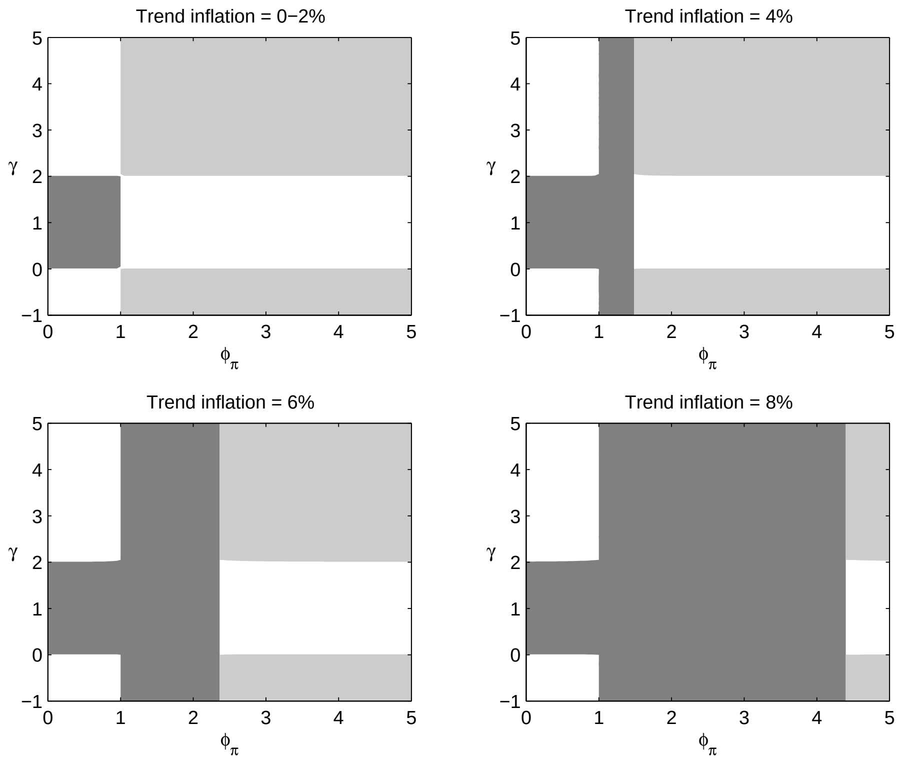

Fig. 3. Determinacy under positive trend inflation and sticky prices
Notes: Indeterminacy: dark grey area; instability: light grey area; determinacy: white area.

Result 2. Trend inflation does not affect determinacy in the PM case (i.e. in the $\phi_\pi < 1$ region).[8]

In particular, when a PM/AF regime is in place, there are two determinate areas: one characterized by low taxes, the other by high taxes. An increase in inflation expectations spurs

[7]For the sake of brevity, we go straight to the more interesting case $\sigma_n = 1$; however, the case $\sigma_n = 0$ gives comparable results and it is available from the authors.

[8]Rossi (2009) obtains the same result employing a model with distortionary taxation and taxes levied on wages.

output and inflation by stimulating a decline in real interest rates. However, the increase in inflation changes the value of real debt and, thanks to wealth effect, drives inflation and thus the economy back to the steady state. Trend inflation does not change these determinacy conditions. Even the PM/PF area remains indeterminate as trend inflation increases.

Result 3. Trend inflation affects determinacy for AM cases.

As can be gauged from Fig. 3, $z(\bar{\pi})$ corresponds to a vertical line to the right of $\phi_\pi = 1$ for inflation targets greater than 2%. In particular, with trend inflation higher than that value, in order to have the AM/PF zone determinate, the central bank has to react more to inflation (i.e. increase ϕ_π).

Under zero trend inflation, in the AM/PF case, the equilibrium is determinate. As trend inflation rises, active monetary policy ($\phi_\pi > 1$) does not guarantee determinacy per se; we instead need monetary policy to be hawkish ($\phi_\pi \gg 1$). Since the output weight in the Phillips curve declines when trend inflation increases, in order to get the desired effect on inflation, the real rate has to increase by a greater extent. The explosive AM/AF area shrinks, as trend inflation increases, together with the determinacy area in the AM/PF case.

From a central bank's perspective, as for determinacy is concerned, the level of inflation that returns the larger area for determinacy in the active monetary case would be around 0-2%.

3.3 Learning under trend inflation

3.3.1 The case of known inflation target

The figures below report the values of the coefficients of monetary and fiscal policy that return E-stability (white area) under opacity (Fig. 4) and transparency (Fig. 5) for different values of trend inflation when the PLM does not include a constant term, which is akin to assume that agents know the inflation target set by the central bank.

The case with zero trend inflation and monetary policy transparency returns results similar to those derived by Evans and Honkapohja (2007) employing the flexible price model by Leeper (1991): in particular, if one disregards, as Evans and Honkapohja do, the top left area (PM/AF$^{\text{up}}$), determinacy implies E-stability. At a first glance, E-stability results are not tightly linked to the determinacy ones. Different trend inflation can have the same determinacy zones but different E-stability ones (compare the cases with trend inflation equal to 0 and 2%).

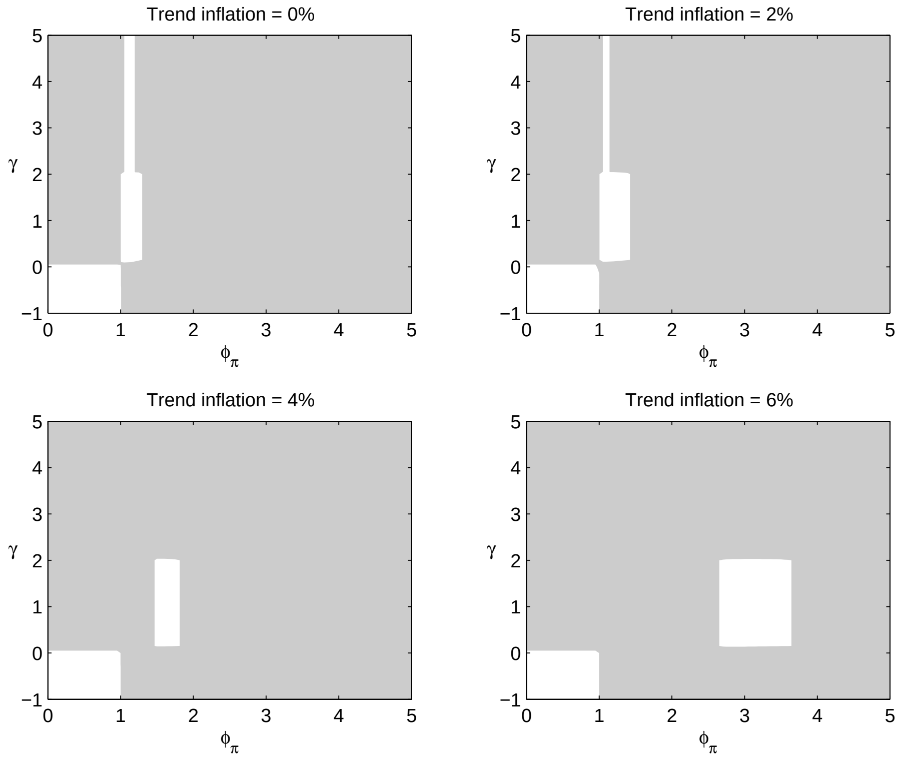

Fig. 4. Learning under monetary policy opacity
Notes: White area: E-stability; grey area: E-instability.

3.3.1.1 Non-Ricardian regimes

Result 4. The area with PM/AF^{up} is always determinate but never E-stable (neither under TR nor under OP); the area PM/AF$_{down}$ is always determinate and always E-stable under both TR and OP.

In both regions, an increase in inflation expectations causes a reduction in real interest rates. These, increasing output, stimulate inflation that, in turn, reduces the value of real debt. Since we are in a non-Ricardian equilibrium, wealth effects are in place but these differ within the two regions. This is due to the fact that the effects of real debt on inflation vary according to the size of the fiscal coefficient γ in the fiscal rule.[9] In the PM/AF$_{down}$ region there is a negative wealth effect that, by decreasing output and inflation, drives the economy back to the steady state stabilizing expectations. Conversely, in the PM/AF^{up} region, when taxes react strongly to

[9] It can be shown that in the PM/AF$_{down}$ region this effect is positive but it weakens as γ increases; in the PM/AF^{up} one the same effect becomes negative.

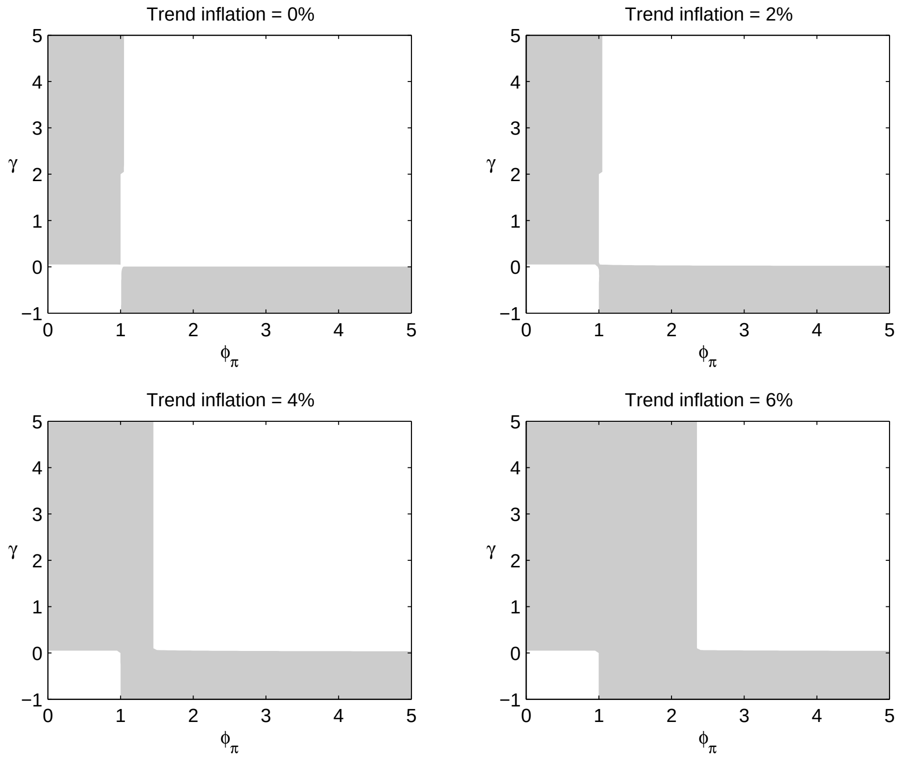

Fig. 5. Learning under monetary policy transparency
Notes: White area: E-stability; grey area: E-instability.

debt, the lower real debt spurs inflation further reducing real rates thus causing an increase in effective output and inflation, consistently higher than expected, and in turn destabilizing the economy.

Result 4 holds for every level of trend inflation. Hence in a non-Ricardian context, determinacy and E-stability conditions are insensitive to changes in trend inflation: E-stability just requires taxes to react weakly to government debt.

3.3.1.2 Ricardian regimes The AM/PF regime, if determinate, is always E-stable under TR, not under OP. Furthermore:

Result 5. Responding aggressively to inflation helps to anchor expectations under TR but not under OP.

After a positive shock to inflation expectations, a transparent central bank, by increasing accordingly the real rate, restraints aggregate demand thus lowering inflation expectations. In this case, thanks to TR, expected real rates equal effective ones and inflation expectations are stabilized.

According to our model, a gap between expected and effective real rates would translate into a gap between expected and effective inflation hence in unanchored inflation expectations. This is what happens under OP when agents fail to anticipate the initial increase of the real rate, even if the central bank follows the Taylor principle. As a result, output rises leading to an increase in inflation that validates the surge in inflation expectations. Since policy responds not to current, but to expected variables, a strong response to expected inflation tends to destabilize the economy. When, in the following periods, agents realise that real rates were higher than expected they revise their real rate expectations upwards. This adjustment is larger the more the central bank previously reacted to inflation. The more the central bank responds to the inflation rate, the more the gap between expected and effective real rates rises, the more agents expectations are destabilized. The closer ϕ_π to 1, the smaller this effect.[10]

3.3.1.3 Uncoordinated regimes If a regime is indeterminate (see the PM/PF case) it is never E-stable; if it is explosive (see AM/AF) can instead be E-stable. In case of TR with AM/AF the explosive solution can be learnable. Therefore the monetary and fiscal authority need not to coordinate their policies if they want to implement a learnable equilibrium. In particular, in case of OP, the regime $\mathrm{AM/AF}^{\mathrm{up}}$ is E-stable just for low values of ϕ_π but E-stability shrinks and gradually disappears as trend inflation rises. The same regime is E-stable under TR but, again, E-stability shrinks as trend inflation rises. $\mathrm{AM/AF}_{\mathrm{down}}$ is never E-stable neither with TR, nor with OP.

3.3.2 The case of unknown inflation target

If we want agents to learn the target as well, we have to consider a model that includes a constant term in the PLM. In this case E-stability additionaly requires that the constant converges to its true value under rational expectations, i.e. zero. The E-stability results when agents know neither the inflation target nor the interest rate rule are presented in Fig. 6, which is unchanged for all the different levels of trend inflation considered in the paper.

Even under this case we have that the area with $\mathrm{PM/AF}^{\mathrm{up}}$ is always determinate but never

[10] For a more detailed explanation of what is going on and for the effects of trend inflation on E-stability under OP see Section 2.3 in the online appendix.

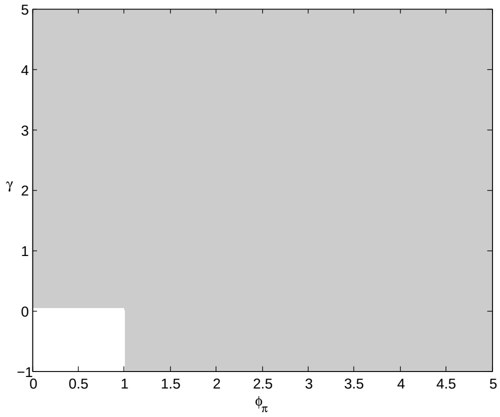

Fig. 6. Learning for unknown inflation target and policy rule, all levels of trend inflation
Notes: White area: E-stability; grey area: E-instability.

E-stable and the area with PM/AF$_{\text{down}}$ is always determinate and E-stable irrespective of the level of trend inflation. However, when agents know the interest rate rule but ignore the inflation target we get, for zero trend inflation, the corresponding picture in Fig. 5[11] while, for every higher trend inflation, we get, again, Fig. 6 above.

Result 6. If there is a positive inflation target and the central bank does not disclose it, there is E-stability just in non-Ricardian regimes with taxes reacting weakly to government debt.

E-stability in the Ricardian case obtains only when the central bank targets a zero inflation rate. Our results for the Ricardian regime differ from Kobayashi and Muto (2013) and Kurozumi (2014) who find E-stability under positive trend inflation when agents ignore the inflation target. Their study, however, is based on contemporaneous expectations (E_t^*) while we maintain the assumption that expectations are formed in $t-1$.[12] As shown in Eusepi and Preston (2010), lagged expectations are a key driver of expectation destabilization when the central bank is not fully transparent.

When agents do not learn the level of trend inflation their misperceptions on trend inflation rate seriously affect macroeconomic stability. As a result, communicating just the inflation target is an important driver for (partially) stabilizing expectations in the Ricardian regime

[11] Note that our analysis is consistent here, under zero trend inflation, with results by Bullard and Mitra (2002) under lagged expectations: for the Ricardian case we have that the determinate region coincides with the expectationally stable region.

[12] In fact, when we assume contemporaneous expectations we find E-stability even under positive trend inflation. See the robustness checks in Section 3.5.

(compare Figs 4 and 6). However, communicating the target in addition to the interest rate rule is crucial to highly improve E-stability (see Fig. 5).

3.4 Impulse response functions

Figures 7 and 8 report impulse response of output, inflation and real debt to, respectively, monetary and fiscal shocks employing the usual calibration (see Table 1) on our model. Each figure is divided in three columns: one for the AM/PF case, one for the PM/AF^{up}, the last for PM/AF$_{down}$.[13] Furthermore, every single impulse response is depicted for different values of trend inflation. Again, our aim is to check if higher values of trend inflation change the responses to shocks when different policy mixes are in place.

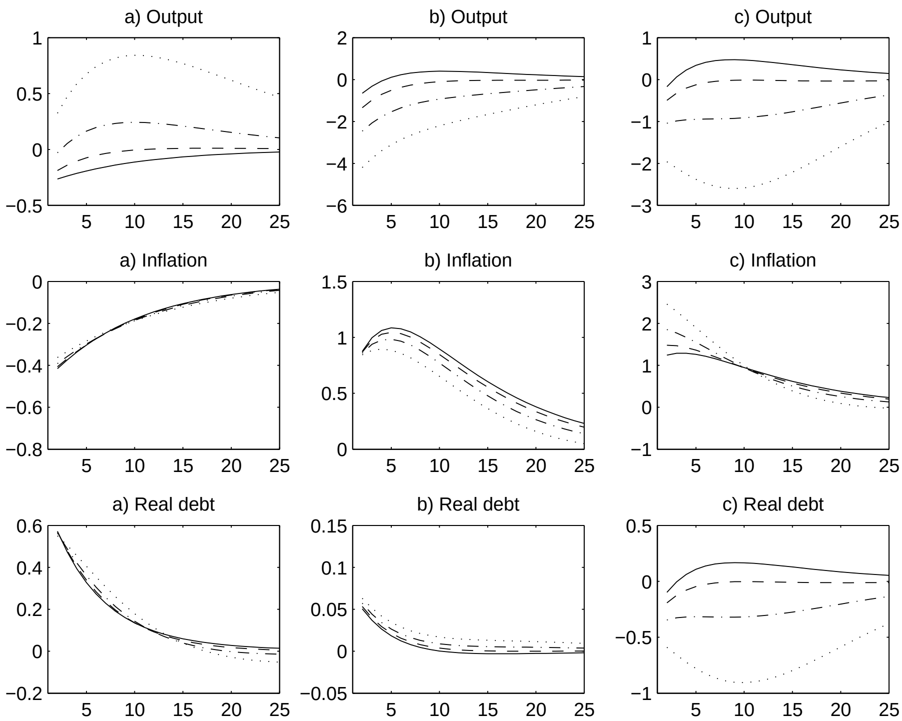

Fig. 7. Impulse response to a contractionary, one standard deviation monetary policy shock
Notes: a) AM/PF ($\phi_\pi = 3, \gamma = 0.2$); b) PM/AF^{up} ($\phi_\pi = 0.5, \gamma = 3$); c) PM/AF$_{down}$ ($\phi_\pi = 0.5, \gamma = 0$). Trend inflation: solid line=0%, dashed=2%, dash-dotted=4%, dotted=6%.

Figure 7 shows the responses to a monetary policy tightening. In the AM/PF regime with

[13] We restrict attention to the two determinate regimes since the double passive and the double active regimes imply, respectively, indeterminacy and no solution. These impulse response are computed under rational expectations. We find them almost identical to the ones obtainable under learning for the E-stable regions. Results are available from the authors upon request.

low levels of trend inflation, both inflation and output decrease on impact, but the contractionary effect on both these variables weakens as trend inflation increases. Moreover, for high levels of trend inflation, not only output reacts less but it even increases on impact causing an 'output puzzle': this is related to the sign change in the Phillips curve slope described by Ascari and Ropele (2009). As already noted by Ascari and Ropele (2007), persistence of the impulse response for both output and inflation increases with trend inflation. In the PM/AF_{down} case, with zero trend inflation, inflation and output rise. An interest rate increase raises the value of government debt to cover the larger interest rate expenses. Agents, in this non-Ricardian setup, perceive the higher debt as net wealth since they do not expect it to be backed up by future taxes hence increase spending and this, in turn, pushes up the price level causing a 'price puzzle'. The higher trend inflation, the more the price puzzle grows while output (through lower real interest rates) and real debt decrease. Conversely, in the PM/AF^{up} zone, the (high) increase in the tax rate causes a negative wealth effect that leads output and inflation to decrease on impact. Lower inflation counteracts the effect of higher taxes making real debt increase. The higher trend inflation, the more output (through lower real interest rates) and inflation decrease bringing about a real debt increase.

A fiscal shock (Fig. 8) does not affect output and inflation under a AM/PF regime since the monetarist solution holds hence their dynamics do not depend on the dynamics of fiscal variables. Higher taxes in the PM/AF_{down} regime cause a negative wealth effect that makes output and inflation decrease. The reduction in prices makes real debt increase. On the other hand, in the PM/AF^{up} regime the initial decrease in debt carried by the shock makes taxes fall by a great extent leading to an increase in output and inflation that, in turn, makes real debt fall. Higher trend inflation tempers the effects on output while, in the PM/AF_{down} case, it exacerbates the debt increase.

3.5 Robustness

In this section we investigate the robustness of our results along different dimensions.[14]

[14]Details on the results, including figures, if not otherwise stated, are omitted for brevity but are available from the authors upon requests.

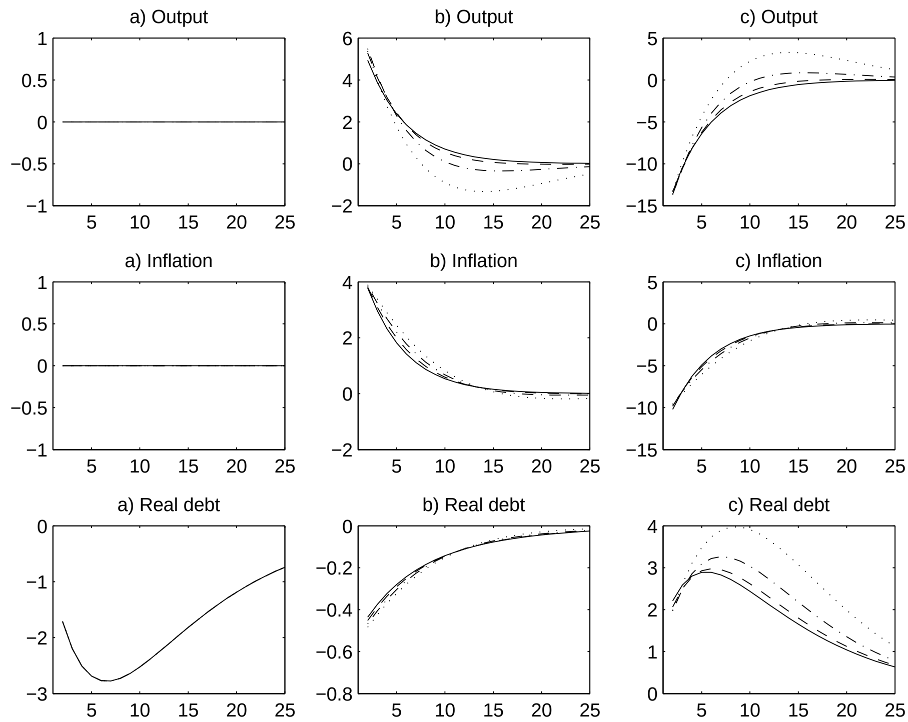

Fig. 8. Impulse response to a contractionary, one standard deviation fiscal policy shock
Notes: a) AM/PF ($\phi_\pi = 3, \gamma = 0.2$); b) PM/AF$^{\text{up}}$ ($\phi_\pi = 0.5, \gamma = 3$); c) PM/AF$_{\text{down}}$ ($\phi_\pi = 0.5, \gamma = 0$). Trend inflation: solid line=0%, dashed=2%, dash-dotted=4%, dotted=6%.

3.5.1 Policy Rule

First, we investigate if and how results change when a different policy rule is considered. A forward looking interest rate rule under flexible prices confirms, even under trend inflation, the results by Branch *et al.* (2008), according to whom determinacy holds provided fiscal policy is active. With a backward looking interest rate rule, instead, determinacy obtains provided the policy mix is PM/AF and this is true for every level of trend inflation. Then Result 1 still holds. Therefore, as in Branch *et al.*, 'for both forward- and backward-looking rules, determinacy implies that the unique rational expectations equilibrium (REE) is non-Ricardian.' Turning to the sticky price model, employing a forward looking rule, irrespective of fiscal policy behaviour, the REE is never determinate under AM as long as trend inflation is positive while Result 2 still holds. As for E-stability, while under zero trend inflation a forward looking rule returns about the same results as the benchmark contemporaneous case, for positive trend inflation, under both TR and OP, the only E-stable regime is the PM/AF$_{\text{down}}$ one. While determinacy results under price rigidity with a backward looking policy rule are similar to the benchmark case, results concerning learning differ. Under both OP and TR the E-stability regions collapse to the benchmark case under transparency.

3.5.2 Learning assumptions

In the paper we maintain the assumption that agents form expectation in $t-1$ and that the central bank reacts to these expectations. As in Eusepi and Preston (2010), this assumption is crucial to study the implications of central bank communications. Indeed, once we assume contemporaneous expectations (E_t^*), any difference between transparency and opacity vanishes, since in this case there is no central bank's information fruitfully exploitable by the public, neither about the inflation target nor about interest rates. Furthermore, while the determinacy regions do not change, the E-stability results, both under known and unknown inflation targets, are equal to the TR case under the E_{t-1}^* specification except for the non-Ricardian region that becomes always learnable.[15]

3.5.3 Model structure

First, we check how results change for different degrees of price rigidity (see figures A2-A7 in the online appendix). We find the degree of price stickiness to be a crucial structural parameter both for determinacy and E-stability. While under flexible prices trend inflation does not affect determinacy, the more rigidity increases (higher α) the more, as trend inflation rises, results differ from the zero inflation case. Furthermore, for $\alpha = 0.91$ the AM/PF mix is never determinate for trend inflation larger than 2%. However, with less rigid prices ($\alpha = 0.35$), we get for determinacy the same results as with flexible prices.[16] What is more, transparency is needed to stabilize expectations in countries with flexible prices since it always sharply improves E-stability with respect to opacity. On the contrary, with high rigidity, TR does not improve relative to OP.

Second, we examine the effects of a higher debt/GDP ratio (in the benchmark case fixed at $\bar{b} = 0.4$). We find that higher levels of $\bar{b}$ do not affect determinacy and only slightly change E-stability results under OP and TR.

[15] E-stability figures under contemporaneous expectations are available from the authors upon request.

[16] The calibration values for high ($\alpha = 0.91$) and low ($\alpha = 0.35$) degree of price rigidity are taken, respectively, from the estimates by Smets and Wouters (2003) for the euro area and by Olivei and Tenreyro (2007) for the United States.

Third, decreasing the value of the elasticity of substitution (θ) weakens the effects of trend inflation on determinacy and on E-stability results. Increasing the intertemporal elasticity of labour supply (σ_n) reduces the E-stability area under both OP and TR and this effect worsens with trend inflation.

Finally, we examine the effects of including price indexation. It is well-known that indexation counteracts the effects of trend inflation. We find that this is true both for determinacy and E-stability.

4 Conclusions

This paper proves that a higher inflation target unanchors expectations under active monetary regimes but not under passive monetary ones. When a central bank, for example, follows a Taylor rule in the Ricardian regime, the higher the inflation target, the smaller the determinacy and the E-stability regions. Moreover, the higher the inflation target, the more the policy should be hawkish with respect to inflation in order to stabilize expectations when the central bank discloses both target inflation and policy response. This is not true in a non-Ricardian context, where determinacy and E-stability are unaffected by changes in trend inflation. Transparency of both the inflation target and the reaction function helps anchoring expectations - returning an E-stability region wider under transparency than under opacity - for all inflation targets under active monetary policy. The AM/PF regime, if determinate, is always E-stable under TR when the inflation target is known; the PM/AF_{down} is always determinate and E-stable. A double active policy with taxes reacting highly to debt can be learnable under transparency. Therefore, with the help of transparency, the monetary and the fiscal authority could coordinate to a lesser extent their policies to get E-stability under learning.

Finally, the more flexible are prices, the more transparency is valuable. In a low price rigidity country, say the United States, adhering to the Taylor principle is a sufficient condition for equilibrium determinacy under the AM/PF regime, irrespective of the level of trend inflation. Still, the central bank must be transparent to stabilize expectations. On the contrary, in a high price rigidity economy, say the euro zone, to have determinacy under AM/PF mix, we find that the inflation target cannot be larger than 2% but the central bank needs not to be transparent to stabilize expectations. Furthermore, high rigidity makes non-Ricardian policies less E-stable.

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Supplementary material

Supplementary material (the Appendix) is available online at the OUP website.

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