



INFORMATION AND EXPECTATIONS IN FISCAL POLICY

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Doctoral Thesis in Economics

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Biographical note

Nuno Vilarinho Gonçalves was born in Porto, Portugal, in 1984. In 2007 he completed undergraduate studies in Financial Management at Instituto Superior de Administração e Gestão. In 2010, after some experience in the private sector, he obtained his master's degree in Economics from the University of Porto with the dissertation "A Economia Não Registada em Portugal". In the same year, he enrolled in the PhD program in Economics at the School of Economics and Management of the University of Porto. During his graduate studies he developed research in the fields of fiscal policy, economic measurement, tax evasion, and informal economy and published work about the shadow economy and informal economy in Portugal. Since November 2014 he works as Economist at the Portuguese Public Finance Council, where he coordinates the Economic Analysis and Forecast area.

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Abstract

Expectations play a key role in transmitting fiscal policy as they affect the behavior of households and firms, for instance, in their savings, investment, production, and employment decisions. The composition of fiscal policy, taxes or spending; its nature, transitory or persistent; and the way it is financed are major determinants of the policy transmission mechanism. The resulting actions from the way economic agents anticipate fiscal policy may, to some extent, depend on the way they form expectations about the future. Rational expectations are the standard assumption in macroeconomics but have been questioned on the grounds of its unrealistically strong restrictions. An alternative framework, that imposes weaker requirements on the agent's information set when making decisions, is adaptive learning. The core idea is that agents form expectations about the future evolution of contemporaneously unobservable variables by engaging in a kind of statistical inference when making their economic choices. Thus, after a policy change, there is a period of uncertainty until agents complete the learning process about the change. Fiscal policy is inevitably embedded in uncertainty as, in many circumstances, choices are made in the absence of complete information either about their design and consequences or about the state of the economy. This thesis analyses and models different ways imperfect information may arise in fiscal policy design and mechanism, as well as the role it might play in the economy.

Using an RBC model with distortionary taxes and government debt, Chapter 1 studies the macroeconomic effects of fiscal policy when agents have imperfect information about the composition of government spending. Agents are assumed to observe total government spending and a noisy public signal regarding the permanent component. The analysis shows that imperfect information lowers the magnitude of the output multiplier for temporary government spending while it rises the magnitude of the output multiplier for permanent government spending. It is also explored how a pure noise shock regarding fiscal policy affects the economy. The results suggest that such shock creates co-movement among output, consumption and hours worked, even without any change in government spending.

Chapter 2 incorporates imperfect information regarding government spending composition – transitory or persistent – into an otherwise typical New Keynesian DSGE model with financial frictions. It concludes that imperfect information amplifies the impact output multiplier of a persistent debt-financed government spending shock, since agents do not fully anticipate the fiscal costs of policy, so the rise in credit spreads, is limited. The results suggest that, for any degree of information, transitory spending policies are more efficient in counteracting a recession as they imply lower output losses. In addition, it is shown that purely fiscal noise shocks have business cycle effects due to the interaction between banks' balance sheet adjustments, leverage constraints and the expectation of future debt-financed fiscal deficits.

Finally, Chapter 3 studies the implications of incomplete information about potential output for the conduct of fiscal and monetary policy, in the context of an optimizing model with nominal rigidities and public debt. Under output gap misperception, optimal fiscal and monetary policies lead to higher stabilization costs for the economy, both under optimal commitment and discretion. Particularly when distortionary taxes are available as policy instrument, there is a clear value of commitment when compared to discretion. Contrarily to what happens under perfect information, it is also shown that higher price rigidity increases welfare losses under imperfect information when policy relies on distortionary taxation.

JEL classification: D80; D83; E17; E44; E52; E62; E63; H30; H60.

Keywords: Fiscal Policy; Government spending; Taxation; Sovereign debt; Economic stabilization; Financial intermediation; Sovereign risk; Potential Output; Optimal Monetary Policy; DSGE; Measurement error; Imperfect information; Expectations; Learning; Uncertainty.

Resumo

As expectativas desempenham um papel fundamental na transmissão da política orçamental, afetando o comportamento dos agentes económicos, nomeadamente nas decisões de poupança, investimento, produção e emprego. Para a transmissão da política orçamental contribuem de forma determinante a sua composição, em impostos ou gastos; a sua natureza, transitória ou persistente; e o modo como é financiada. A antecipação da política orçamental por parte dos agentes económicos e consequente comportamento, podem depender, em parte, da maneira como estes geram expectativas sobre o futuro. As expectativas racionais são o pressuposto comum na teoria macroeconómica, apesar das suas restrições irrealisticamente fortes terem vindo a ser questionadas. Consequentemente, a aprendizagem adaptativa (*adaptive learning*) surge como uma estrutura alternativa, que impõe requisitos mais fracos ao conjunto de informação do agente quando este toma decisões. A ideia de base assenta na formação de expectativas pelos agentes sobre a evolução futura de variáveis, não observáveis contemporaneamente, realizando uma espécie de inferência estatística quando tomam decisões económicas. Assim, após uma mudança de política, há um período de incerteza até que os agentes concluem o processo de aprendizagem sobre essa mudança. A política orçamental está inevitavelmente envolta em incerteza dado que, em muitas circunstâncias, são tomadas decisões na ausência de informação completa sobre o desenho e consequências das políticas assim como quanto à situação da economia. Esta tese analisa diferentes formas de informação imperfeita que podem surgir no desenho e mecanismo das políticas orçamentais, bem como o papel que podem desempenhar na economia.

Recorrendo a um modelo *Real Business Cycle* com impostos distorcionários e dívida pública, o Capítulo 1 estuda os efeitos macroeconómicos da política orçamental quando os agentes têm informação imperfeita acerca da composição dos gastos públicos. Por hipótese, os agentes observam o total de gastos do governo e um indicador com ruído da componente permanente dos gastos. A análise demonstra que a informação imperfeita diminui a magnitude do multiplicador da componente temporária dos gastos públicos e aumenta a magnitude do multiplicador dos gastos permanentes do governo. São também explorados os efeitos na economia de um choque no sinal da componente permanente dos gastos. Os resultados sugerem que tal choque cria co-movimento entre produto, consumo e horas trabalhadas, mesmo na ausência de variação nos gastos públicos.

No Capítulo 2 é incorporada informação imperfeita acerca da composição dos gastos públicos – transitórios ou persistentes – num modelo DSGE Neo-Keynesiano com fricções financeiras. Conclui-se que a informação imperfeita amplifica no impacto o multiplicador de um choque persistente nos gastos públicos financiado através de dívida, uma vez que os agentes não antecipam completamente o custo fiscal da política, levando a um aumento limitado nos *spreads* de crédito. Os resultados sugerem que, para qualquer grau de informação, políticas de gastos públicos de cariz transitório são mais eficientes no combate a uma recessão, uma vez que implicam menores perdas no produto da economia. Adicionalmente, demonstra-se que choques sem fundamento nos gastos públicos (choques no sinal da componente persistente) têm efeitos no ciclo económico devido à interação entre ajustes no balanço dos bancos, restrições de alavancagem na carteira dos bancos e a expectativa de futuros défices orçamentais financiados por dívida.

Por fim, o Capítulo 3 estuda as implicações da existência de informação incompleta sobre o produto potencial para a condução da política orçamental e monetária, no contexto de um modelo de otimização com rigidez nominal e dívida pública. Na presença de erros de perceção acerca do hiato do produto, as políticas orçamental e monetária ótimas levam a custos de estabilização mais elevados para a economia, quer na solução sob compromisso (*commitment*), quer na solução discricionária ótimas. Em particular, quando impostos distorcionários estão disponíveis como instrumento de política, existe um claro valor da solução sob compromisso quando comparada com a discricionária. É também demonstrado que a maior rigidez de preços aumenta as perdas de bem-estar na economia em informação imperfeita quando a política depende de impostos distorcionários, contrariamente ao que acontece quando a informação é perfeita.

Classificação JEL: D80; D83; E17; E44; E52; E62; E63; H30; H60.

Palavras-chave: Política Orçamental; Dívida soberana; Estabilização económica; Intermediação financeira; Risco da dívida soberana; Produto potencial; Política monetária ótima; DSGE; Erro de medição; Informação imperfeita; Expectativas; Aprendizagem; Incerteza.

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Chapter 1

Fiscal Policy with Imperfect Information

1.1 Introduction

The increasing resort to large fiscal stimulus by governments all over the world in response to the 2008 global recession has been asserting the importance of fiscal policy as a macroeconomic stabilization tool. Nonetheless, when economic agents are imperfectly informed about the fiscal stimulus or are uncertain about its timing, economic outcomes and the way it will be financed, the efficiency of fiscal policy could be distorted since expectations may play a moderating role. This paper studies how expectations and expectational errors caused by information imperfections may shape fiscal policy macroeconomic outcomes.

The last decade observed a revival in the literature on the role of expectations as a source of business cycle fluctuations, owing its foundations to the work of Pigou (1927) and Keynes (1936).¹ In the fiscal policy literature, the role of news and the anticipation of fiscal changes that will occur at some future date have been emphasized under the fiscal foresight topic (*e.g.*, Yang, 2005; Walker and Leeper, 2011; Ramey, 2011b; Leeper et al., 2012; Mertens and Ravn, 2012; and Leeper et al., 2013). This news-driven literature differs from the noise-driven business cycle literature, such as Woodford (2003), Lorenzoni (2009), Angeletos and La'O (2010), and Blanchard et al. (2013). In a news-driven economy the effects are due to the effective anticipation of future policy, whereas in a noise-driven economy there are fluctuations merely due to the reaction to non-fundamental shocks. This paper

¹See, among others, Beaudry and Portier (2004, 2006); Jaimovich and Rebelo (2009); Barsky and Sims (2011); Christiano et al. (2012); Schmitt-Grohé and Uribe (2012); Angeletos and La'O (2013).

attempts to contribute to: (i) the literature on noise-shocks, by emphasizing the difference between fundamental and noise shocks in fiscal policy; and (ii) to the literature on fiscal policy effects, specially that focused on the difference between the effects of permanent and temporary fiscal shocks (*e.g.*, Aiyagari et al., 1992; Baxter and King, 1993; Hall, 2009; and Barro and Redlick, 2011),² by applying Brunner et al. (1980) and Kydland and Prescott (1982) idea that agents could not differentiate in real time between transitory and permanent shocks, to a fiscal policy decomposition problem.

For that purpose, this paper develops a Real Business Cycle (RBC) model with distortionary taxation and government debt where, following Barro (1981) and Aiyagari et al. (1992), among others, government expenditure is theoretically divided into permanent and temporary components. Labor income and capital income tax rates are assumed to be equal and to follow a rule that, in accordance with Barro (1979) tax-smoothing theory, is a function of the permanent component of government expenditure. The representative agent observes all the past and current total government expenditure shocks and knows the stochastic properties of the distributions of permanent and temporary components, but does not observe the realizations of each component. Using all the available information, the representative agent forms expectations about each component of government expenditure shocks using the Kalman Filter.

The model embeds two signals that reveal information about both unobserved components of government expenditure: the total government expenditure and an additional noisy signal that provides information about the permanent component. It is owing to this last signal that, in this model framework, agents try to disentangle fundamental shocks from pure noise shocks.³ These noise shocks lead agents to temporarily overestimate or underestimate the true permanent government expenditure component, consequently triggering aggregate fluctuations.

The motivation for introducing a learning problem in the decomposition of total government expenditure into permanent and temporary components relies, on the one hand, on fiscal transparency issues (*e.g.*, Kopits and Craig, 1998; Alesina and Perotti, 2008), which advocate that the budget complexity allied with nontransparent procedures can strategically influence the beliefs and the information of taxpayers regarding the status and the future of public finances. On the other hand, as Baker

²For a comprehensive review on the literature about the effects of government spending, see Ramey (2011a) and the references therein.

³This noisy signal allows us to vary the degree of imperfect information while keeping all other structural parameters unchanged.

et al. (2011) argue, the task of disentangling permanent from temporary changes in fiscal policy is identified as a major source of fiscal policy uncertainty.

Since in this model households face a signal-extraction problem, the present analysis is closely related to a number of papers in which fiscal policy is formalized in a signal-extraction environment. This literature includes Giannitsarou (2006), Evans et al. (2009), Eusepi and Preston (2012), Mitra et al. (2013), Gasteiger and Zhang (2014), and Hollmayr and Matthes (2015). During the development of this paper Fève and Pietrunti (2016) studied, in a closely related paper, the macroeconomic implications of fiscal policy in a setting in which private agents receive noisy signals about future shocks to government expenditures.⁴ The authors conclude that the existence of noise implies a sizable difference in fiscal multipliers when the government seeks to implement a persistent change in expected public spending. The present framework is distinct from this literature in one particular aspect – agents know how the economy and the fiscal rule are structured although they need to learn about the composition of the fiscal shock, which, by nature, has different effects on the way expenditure is financed, and by consequence on the expected distortionary tax rate.

Secondly, the way uncertainty is defined, according to the nature of fiscal shocks, also differentiates this paper from another strand of literature on fiscal policy under uncertainty, which includes Davig et al. (2010), Bi et al. (2013), Johannsen (2014), Born and Pfeifer (2014), and Fernández-Villaverde et al. (2015). In this regard, a key contribution of our paper is the emphasis on the role of expectations in fiscal policy through a “noise” channel. In our model, treating noise shocks akin to fiscal transparency/uncertainty shocks allows us to evaluate the fiscal policy outcomes under different degrees of imperfect information (fiscal transparency). From a policy point of view, this question could be useful to assess the role of fiscal councils in shaping fiscal sustainability and fiscal outcomes (*e.g.*, Debrun et al., 2009).

The rest of the paper is structured as follows. Section 1.2 introduces the model, the information structure and the consequent learning process. Section 1.3 presents the results from the numerical simulation and the evaluation of fiscal policy under perfect and imperfect information. Section 1.4 concludes.

⁴Quaghebeur (2018) also studied the government spending multiplier when economic agents combine adaptive learning and knowledge about future fiscal policy to form their expectations, concluding that the effects of a government spending shock substantially change when the rational expectations hypothesis is replaced by this learning mechanism. Although, the study do not focus on different type of government spending shocks or noise shocks.

1.2 Theoretical Framework

The model described in this section is a baseline RBC model, similar to that used by Ludvigson (1996) and Burnside et al. (2004) among others. In the model setup, government expenditures are theoretically divided into permanent and temporary components. There is uncertainty in the economy about the contributions of temporary and permanent shocks to observed total government expenditure. Moreover, the observation of a noisy public signal regarding the permanent component allows agents to solve a signal extraction problem. The economy's dynamic behavior analysis focus on the effects of the "noise shock", which corresponds to the noise component in the public signal.

1.2.1 Household Behavior

The households in the economy maximize a discounted expected utility, given by

$$U = E_t \sum_{i=0}^{\infty} \beta^i \left[\log(C_{t+i}) + \frac{\theta}{1 - \varphi_n} (1 - N_{t+i})^{1 - \varphi_n} \right], \quad (1.1)$$

where E_t denotes the expectations operator conditional on information known at time t , while C_t and N_t denote time t household consumption and household labor supply, respectively. Households discount future utility by a factor β per period. Finally, $\frac{1}{\varphi_n} > 0$ represents the elasticity of leisure relative to real wage.

The household owns the stock of capital, whose value at the beginning of time t is denoted by K_t , and in absence of adjustment costs evolves according to

$$K_{t+1} = I_t + (1 - \delta) K_t,$$

given the depreciation rate δ , and where I_t denotes investment in capital at time t .

Denoting real wage per unit of labor by W_t and the real rate on capital by r_t^k , the agent maximizes his or her lifetime utility 1.1 at each period t over C_t , N_t , K_t , and real government debt holdings (D_t), subject to the following budget constraint:

$$C_t + I_t + D_t = (1 - \tau_t) (W_t N_t + r_t^k K_{t-1}) + (1 + R_t^D) D_{t-1},$$

where R_{t-1}^D and τ_t denote, respectively, gross interest rate on government debt and income tax rate.⁵

This yields the following set of first order conditions:

⁵It is implicit that the labor income tax rate and the capital income tax rate are the same.

$$\begin{aligned}
C_t &= \frac{1}{\beta} E_t \left[C_{t+1} \frac{1}{1 + R_{t+1}} \right], \\
C_t &= \frac{1}{\beta} E_t \left[C_{t+1} \frac{1}{1 + R_{t+1}^D} \right], \\
W_t &= \frac{\theta (1 - N_t)^{-\varphi_n} C_t}{1 - \tau_t},
\end{aligned}$$

where

$$1 + R_t^D = 1 + R_t = E_t [(1 - \tau_t) r_t^k] + (1 - \delta).$$

1.2.2 Firm Behavior

Output (Y_t) production takes place in a competitive sector of firms, each of which using a production function of the Cobb-Douglas type which explicitly incorporates labor, N_t , capital, K_{t-1} , and a labor augmenting technology parameter, A_t ,

$$Y_t = (A_t N_t)^\alpha K_{t-1}^{1-\alpha}.$$

The representative firm sells its output in a perfectly competitive goods market and rents capital and labor from the household in perfectly competitive spot markets to maximize profit given by

$$Y_t - W_t N_t - r_t^k K_{t-1}^{1-\alpha}.$$

Profit optimization results in the usual first-order conditions, where wages (W_t) and capital rental rents (r_t^k) are given by

$$\begin{aligned}
W_t &= \alpha \frac{Y_t}{N_t}, \\
r_t^k &= (1 - \alpha) \frac{Y_t}{K_{t-1}}.
\end{aligned}$$

Technology is assumed to follow a stationary exogenous nonstochastic process that evolves at the constant gross rate $\bar{X} = A_t/A_{t-1}$. It is the driving variable of steady state growth.

1.2.3 Fiscal Policy

The government budget constraint is:

$$D_t = G_t - \tau_t Y_t + (1 + R_t^D) D_{t-1}.$$

Government expenditure, G_t , financed by distortionary income taxes and government debt, is composed by a transitory component, G_t^T , and a permanent component, G_t^P ,

$$G_t = G_t^T + G_t^P. \quad (1.2)$$

Let us express $g_t = (G_t - \bar{G})/\bar{Y}$, $g_t^i = (G_t^i - \bar{G})/\bar{Y}$, $i = T, P$, $d_t = (D_t - \bar{D})/\bar{Y}$ as deviations from steady state relative to steady state output, and $\tilde{\tau}_t = (\tau_t - \bar{\tau})$ as percentage points deviations from steady state. The transitory component follows an AR(1) process

$$g_t^T = \rho_T g_{t-1}^T + \varepsilon_t^T, \quad (1.3)$$

and the permanent component follows a unit root process:⁶

$$g_t^P = (\rho_P + 1) g_{t-1}^P - \rho_P g_{t-2}^P + \varepsilon_t^P. \quad (1.4)$$

The coefficients ρ_T and ρ_P are in $[0, 1)$ and ε_t^T and ε_t^P are i.i.d. normal shocks with zero mean and variances σ_T^2 and σ_P^2 , respectively. In the case of identical autocorrelation coefficients, $\rho_P = \rho_T = \rho$, as it is assumed throughout the paper,⁷ the variances of both shocks are linearly dependent satisfying

$$\rho \sigma_P^2 = (1 - \rho)^2 \sigma_T^2 \equiv \sigma_G^2,$$

where σ_G^2 denotes the variance of total government expenditure g_t .

It is assumed that the income tax rate, in log-linearized terms, verifies a fiscal policy rule of the form

⁶This process makes the model non-stationary after detrended. In order to ensure stationarity to the government expenditure to output ratio, expression (1.4) was changed to $g_t^P = \rho_{P1} g_{t-1}^P - \rho_{P2} g_{t-2}^P + \varepsilon_t^P$, and ρ_{P1} and ρ_{P2} were calibrated such that the AR(2) is stationary and guarantees that g_t^P converges to the steady state only in the long run, in order to mimic the properties of a permanent shock during the period under analysis. Since after this test the transformation did not changed significantly the results and the model with the unit root process is stable, this paper proceeds with the process denoted in (1.4).

⁷Due to the lack of empirical evidence on the decomposition, this is a simplifying and technically useful assumption to model both temporary and permanent component in order to make them dependent, in terms of parameters, on the total government expenditure ratio.

$$\tilde{\tau}_t = \phi_G \Gamma(g_t) + \phi_D d_{t-1}, \quad (1.5)$$

where ϕ_G and ϕ_D are positive constants. The main difference from other simple rules commonly used in the literature (*e.g.*, Galí et al., 2007), is that the tax rate will respond to the permanent expenditure component instead of the total expenditure or output. The motivation for this rule, on the one hand, arises from Barro (1979) tax-smoothing theory, where the tax rate is a function of the permanent component of government expenditures and the debt service. On the other hand, it will assume an important role in the transmission mechanism of the effects of imperfect information. This rule also entails the stabilization function of the debt.

In this framework, the function is represented by the following expression

$$\Gamma(g_t) = \lim_{j \rightarrow \infty} E_t[g_t] = \lim_{j \rightarrow \infty} E_t[g_{t+j}^P + g_{t+j}^T].$$

Since the temporary component disappears in the long run, for j large enough one have

$$\Gamma(\cdot) = \lim_{j \rightarrow \infty} E_t[g_{t+j}^P].$$

The expected value of cumulated long-run government expenditure can computed as follows

$$\lim_{j \rightarrow \infty} E_t[g_{t+j}^P + g_t^P] = \frac{\rho}{1-\rho} E_t[g_t^P + g_{t-1}^P].$$

Hence, the expected fiscal policy rule (1.5) yields

$$\tilde{\tau}_t = \frac{\phi_G}{1-\rho} [E_t(g_t^P) - \rho E_t(g_{t-1}^P)] + \phi_D d_{t-1}. \quad (1.6)$$

To close the model, aggregate resource constraint is given by

$$Y_t = C_t + I_t + G_t.$$

1.2.4 Equilibrium

The equilibrium of this economy is defined in the usual way. The detrended equations are log-linearized around the steady state, where small-caps variables denote log-deviations from steady state, *e.g.*, $c_t = \log(C_t/A_t) - \log(\bar{C}/\bar{A})$. Production and feasibility are

$$y_t = \alpha n_t + (1 - \alpha) k_{t-1},$$

$$y_t = \frac{\bar{C}}{\bar{Y}} c_t + \frac{\bar{I}}{\bar{Y}} i_t + g_t.$$

The labor market equilibrium is given by

$$w_t = \varphi_n \left(\frac{\bar{N}}{1 - \bar{N}} \right) n_t + \left(\frac{1}{1 - \bar{\tau}} \right) \tilde{\tau}_t + c_t,$$

$$w_t = y_t - n_t.$$

Linearization of the government budget constraint around a non-zero debt to output ratio yields

$$d_t = \frac{\bar{R}}{\bar{X}} d_{t-1} + \frac{\bar{D} \bar{R} - 1}{\bar{Y} \bar{X}} r_t^D + g_t - \tilde{\tau}_t - \bar{\tau} y_t. \quad (1.7)$$

After the linearization of (1.2) around a steady state where $\bar{g}^T = 0$ and $\bar{g}^P = \bar{g} = \frac{\bar{G}}{\bar{Y}}$, the government expenditure expressed as deviations from steady state relative to steady state output is given by

$$g_t = g_t^T + g_t^P. \quad (1.8)$$

Plugging in (1.7) the fiscal policy rule (1.6) and expression (1.8) yields

$$d_t = \left(\frac{\bar{R}}{\bar{X}} - \phi_D \right) d_{t-1} + \frac{\bar{D} \bar{R} - 1}{\bar{Y} \bar{X}} r_{t-1}^D + g_t - \frac{\phi_G}{1 - \rho} [E_t(g_t^P) - \rho E_t(g_{t-1}^P)] - \bar{\tau} y_t. \quad (1.9)$$

In this model, for a non-explosive debt dynamics, a necessary and sufficient condition is given by

$$\phi_D > \frac{\bar{R}}{\bar{X}} - 1.$$

Finally, capital accumulation, returns and consumption satisfy

$$\begin{aligned}
k_t &= \frac{\bar{I}}{\bar{K}} i_t + \frac{1-\delta}{\bar{X}} k_{t-1}, \\
\hat{r}_t^K &= y_t - k_{t-1}, \\
r_t^D = r_t &= E_t \left[(1 - \bar{\tau}) \hat{r}_t^k + \tilde{\tau}_t \right] \frac{\bar{r}^k}{\bar{R} - 1}, \\
c_t &= E_t [c_{t+1}] - \frac{\bar{R} - 1}{\bar{R}} r_{t+1}.
\end{aligned}$$

1.2.5 Imperfect Information

The economy is embedded with imperfect information about the true decomposition of government expenditure shocks into permanent and temporary component. The hypothesis is similar to Brunner et al. (1980) and Kydland and Prescott (1982), who assumed that agents could not differentiate in real time between transitory and permanent shocks, although the idea is applied to a fiscal policy decomposition problem. The motivation to apply this framework lays behind budget complexity and fiscal transparency issues that raise fiscal uncertainty in the economy.

The uncertainty in public finance may be due to uncertainty in the way public expenditure will be financed, lack of transparency regarding local government public finance or public enterprises financial position, or political instability that generates uncertainty in future structural reforms or ongoing government investment. In this context, agents fail to perfectly observe the actual composition of the expenditure. Hence, they are unaware about the way it will be financed, so they need to make conjectures about it. Each period, current total government expenditure ratio, g_t , and a noisy public signal, s_t , regarding the permanent component of the expenditure process are observed in the economy

$$s_t = g_t^P + \varepsilon_t^s,$$

where ε_t^s is i.i.d., normal, with zero mean and variance σ_s^2 .⁸ ε_t^s is a non-fundamental noise shock which prevents, in the model, the perfect identification of permanent innovations to government expenditure and generates an independent source of variation in the beliefs regarding g_t^P . Since information is symmetric, the government shares the same information set and, consequently, set the average tax rate given the beliefs about the permanent component of government expenditure.

⁸The three shocks considered in the model (ε_t^P , ε_t^T , and ε_t^s) are mutually independent.

Let $x_{t|t}$ denote the agent or government expectation regarding the variable x_t based on the information set at date t , *i.e.*, $E_t[x_t] \equiv x_{t|t}$. Using this definition, the fiscal rule (1.6) yields

$$\tilde{\tau}_t = \frac{\phi_G}{1-\rho} [E_t(g_{t|t}^P) - \rho E_t(g_{t|t-1}^P)] + \phi_D d_{t-1}.$$

The information structure captures the notion that the government and the agents form erroneous beliefs about unobserved fundamentals of the economy and thereby influence short-run fluctuations.

Having observed the total government expenditure ratio and the signal, the update of the beliefs about the permanent and the temporary component of government expenditure is made using a Kalman filter similar to Woodford (2003), Lorenzoni (2009), Boz et al. (2011) and Blanchard et al. (2013). Because the system of equations is linear and all shocks are Gaussian, the Kalman filter ensures that agents process available information in the most efficient way. The beliefs follow the law of motion

$$\begin{bmatrix} g_{t|t}^P \\ g_{t-1|t}^P \\ g_{t|t}^T \end{bmatrix} = \mathbf{A} \cdot \begin{bmatrix} g_{t-1|t-1}^P \\ g_{t-2|t-1}^P \\ g_{t-1|t-1}^T \end{bmatrix} + \mathbf{B} \cdot \begin{bmatrix} g_t \\ s_t \end{bmatrix}.$$

where the matrices $\mathbf{A}$ and $\mathbf{B}$ depend on the underlying parameters (see Appendix 1.A).

1.3 Model Analysis

The model calibration is first presented and then the implications of introducing imperfect information in the propagation of fiscal shocks are analyzed.

1.3.1 Calibration

For the calibration of the standard parameters and steady state values of the RBC model, it is assumed that the time period in the model corresponds to one-quarter. The discount factor β is set equal to 0.99 and the rate of depreciation $\delta = 0.025$. The elasticity of output with respect to hours is assumed to be $\alpha = 0.667$. The economy's growth in the balanced growth path is given by the trend $\bar{X} = 1.005$. Following Burnside et al. (2004), the baseline value for φ_n is set equal to 1, which implies the utility function for leisure is logarithmic, and $\bar{N} = 0.24$, meaning that the representative agent spends 24% of his/her time endowment working.

Regarding the parameters that describe fiscal policy it is used the U.S. quarterly data from 1966Q1 to 2008Q1 for calibration.⁹ The steady state level of spending is $\overline{G}/\overline{Y} = 0.2466$ which, together with $\overline{D}/\overline{Y} = 1.8776$, a debt-to-GDP steady state ratio of 46,9% in annual terms, yields $\overline{\tau} = 0.2646$. This implies $\overline{Y}/\overline{K} = 0.1634$, $\overline{I}/\overline{Y} = 0.1827$ and $\overline{C}/\overline{Y} = 0.5707$. Regarding ρ it is attributed the value of 0.8, which confers a considerable persistency to the temporary shock and allows the permanent component to reach the peak of ratio after a shock in approximately 30 quarters (*i.e.*, seven years). Since there is a focus on the permanent component of government expenditure, in which a shock mostly implies structural changes in the economy, it seems reasonable to model the variable in such a way. For the standard deviation of the government expenditure ratio, σ_G , the value of 4 is consistent with the data. Regarding σ_s , it is set the value depending on the signal-to-noise ratio, $\nu = \sigma_G/\sigma_s$, starting with a calibration of $\nu = 1$ (benchmark model) and making a sensibility analysis for a ratio smaller and greater than one, implying, respectively, greater and smaller imperfect information. In what concerns the fiscal rule, the parameters associated with the debt stabilization and the government expenditure are $\phi_D = 0.10$ and $\phi_G = 0.50$ for the benchmark model, based on the average values found in Leeper et al. (2010).¹⁰

The sensibility analysis developed below focuses on the impact multiplier and its interactions with parameters φ_n , ϕ_G , ϕ_D and, most importantly, the degree of imperfect information ν .

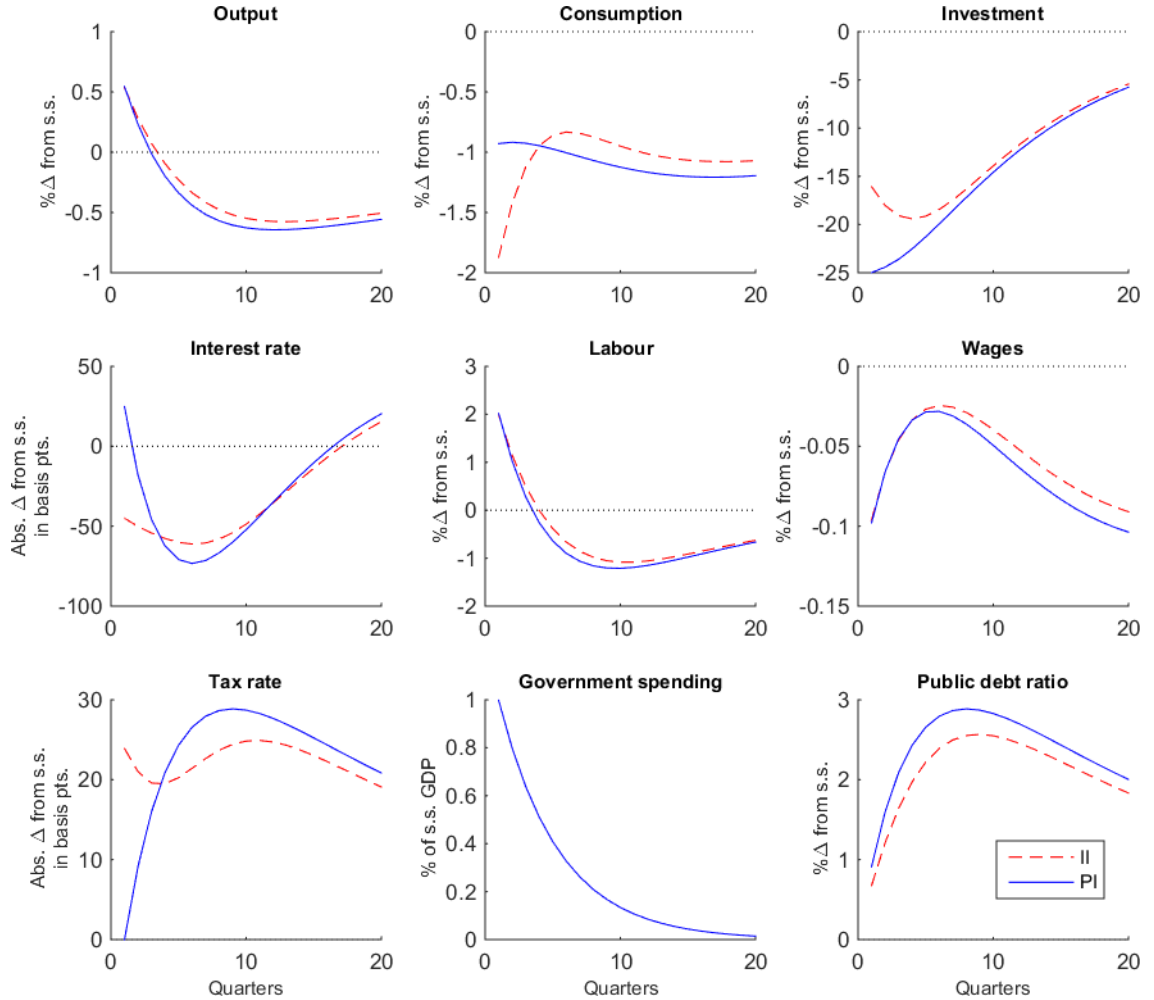
1.3.2 Fiscal shocks

This section examines the effects of a shock in the temporary and permanent components of government expenditure under imperfect information, and compare the same shocks when perfect information prevails.

⁹Data from FRED economic data, using time series for Gross Domestic Product; Government Consumption Expenditures & Gross Investment; Federal National Defense Government Consumption Expenditures; and Total Public Debt as Percent of Gross Domestic Product.

¹⁰Although in Leeper et al. (2010) the tax rate rules do not include government expenditure explicitly, their model considers government investment (structural by nature) and the reaction of tax rules to output.

Figure 1.1: Impulse responses to a 1% GDP positive shock in temporary government expenditure

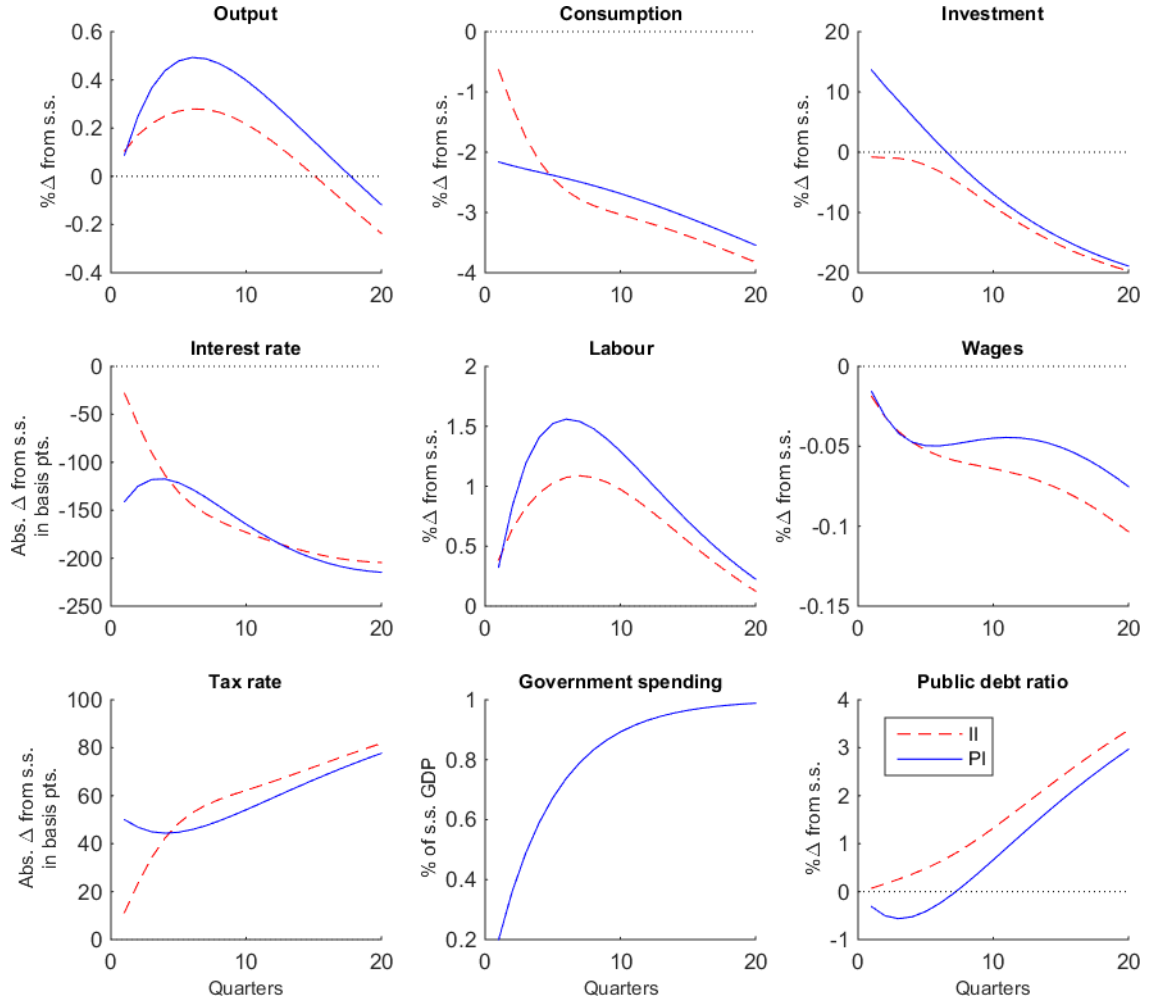


Note: solid lines correspond to the model with perfect information (PI) and dashed lines to the benchmark model with imperfect information (II) ($\phi_G = 0.50$; $\phi_D = 0.10$; $\nu = 1$).

Figure 1.1, plots the impulse responses following an exogenous 1% of GDP increase in the temporary component of government expenditure. Solid lines mimic the standard responses in a prototypical RBC model: a temporary increase in government spending reduces wealth, increasing work effort and, consequently, output. Government spending crowds out investment and its negative wealth effect leads consumption to decline. These effects naturally depend on how expenditure is financed, by means of distortionary taxation or debt issuing.¹¹

¹¹See section 1.3.5, below and Figures 1.5, 1.6 and 1.7, for the results of the benchmark model with different values assigned to ϕ_G and ϕ_D .

Figure 1.2: Impulse responses to a 1% GDP positive shock in permanent government expenditure



Note: solid lines correspond to the model with perfect information and dashed lines to the benchmark model with imperfect information ($\phi_G = 0.50$; $\phi_D = 0.10$; $\nu = 1$).

Under imperfect information, agents need to learn about the nature of the shock, which requires learning about the way government expenditure is financed. Figure 1.1 illustrates this learning process (dashed lines). When the shock hits the economy, the representative agent is unable to fully distinguish if the expenditure is of temporary or permanent nature. Hence, after the shock, the effect in the expected tax rate is higher under imperfect information. The perception of a deeper negative wealth effect reduces the effect on output and amplifies the negative effect on consumption. The crowd out effect on investment is lessened. During the transition dynamics, government debt is lower under imperfect information.

A positive shock in the permanent component of government expenditure (Figure 1.2) corresponds to a permanent negative wealth shock, leading, in the long run, to

a permanent negative effect on output, consumption and investment. The short-run response of output under perfect information is positive, despite the small impact multiplier compared to the temporary shock. The drop in consumption implies higher savings, leading to a temporary rise in investment and drop in interest rate. The rise in distortionary taxes motivates the rise of labor supply and the fall in wages. These effects are not as strong as in Baxter and King (1993) due to the presence of government debt in this model. Under imperfect information, agents are not able to immediately identify the negative wealth effect. Therefore, the tax rate is underestimated and output responds slightly more positively to the shock. Labor supply is positive, causing wages to fall. Consumption fails to drop as much as under perfect information, leading to lower savings, and as investment is crowded out the interest rate drops less. The government debt is higher under imperfect information reflecting lower taxation.

1.3.3 Fiscal multipliers

To assess the potential impact of imperfect information on fiscal policy efficiency this paper studies how this affects fiscal multipliers implicit on the benchmark model. Following Uhlig (2010), the net present value fiscal multiplier for government expenditure at time t can be computed using the expression:

$$M_t = \frac{\sum_{j=0}^t \bar{R}^{-j} y_j}{\sum_{j=0}^t \bar{R}^{-j} g_j}.$$

Figure 1.3: Output multiplier after a 1% GDP shock in government spending temporary and permanent components

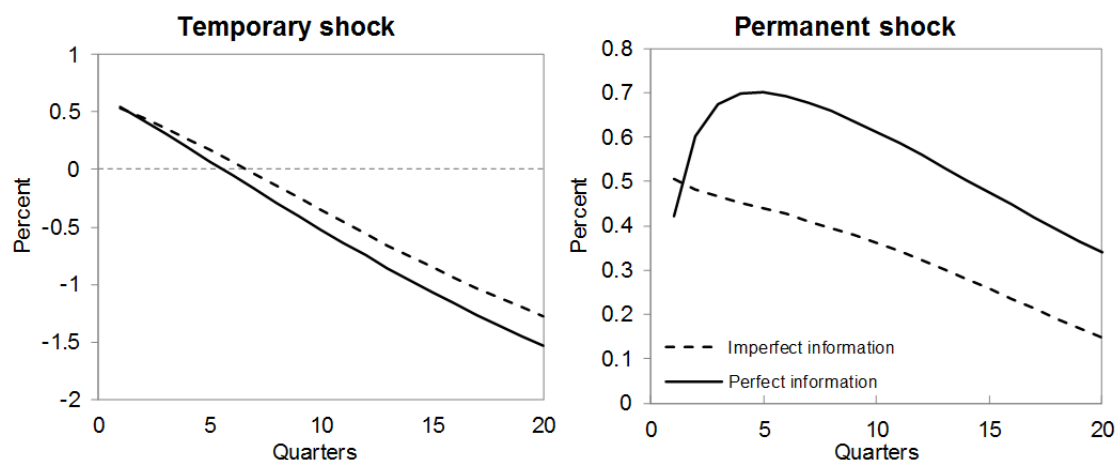


Table 1.1: Government Spending Multipliers				
	Quarter 1	Quarter 4	Quarter 12	Quarter 20
<i>Temporary shock</i>				
PI	0.54	0.19	-0.75	-1.54
II	0.53	0.27	-0.56	-1.28
<i>Permanent shock</i>				
PI	0.42	0.70	0.56	0.34
II	0.51	0.45	0.32	0.15

Note: PI – perfect information; II – imperfect information.

Figure 1.3 and Table 1.1 show that a positive shock on the temporary component of government expenditure leads to a positive multiplier in the first quarter, that is marginally larger under perfect information in the short run. In the long run both multipliers under perfect and imperfect information are negative, although under imperfect information the multiplier exhibits larger negative values.

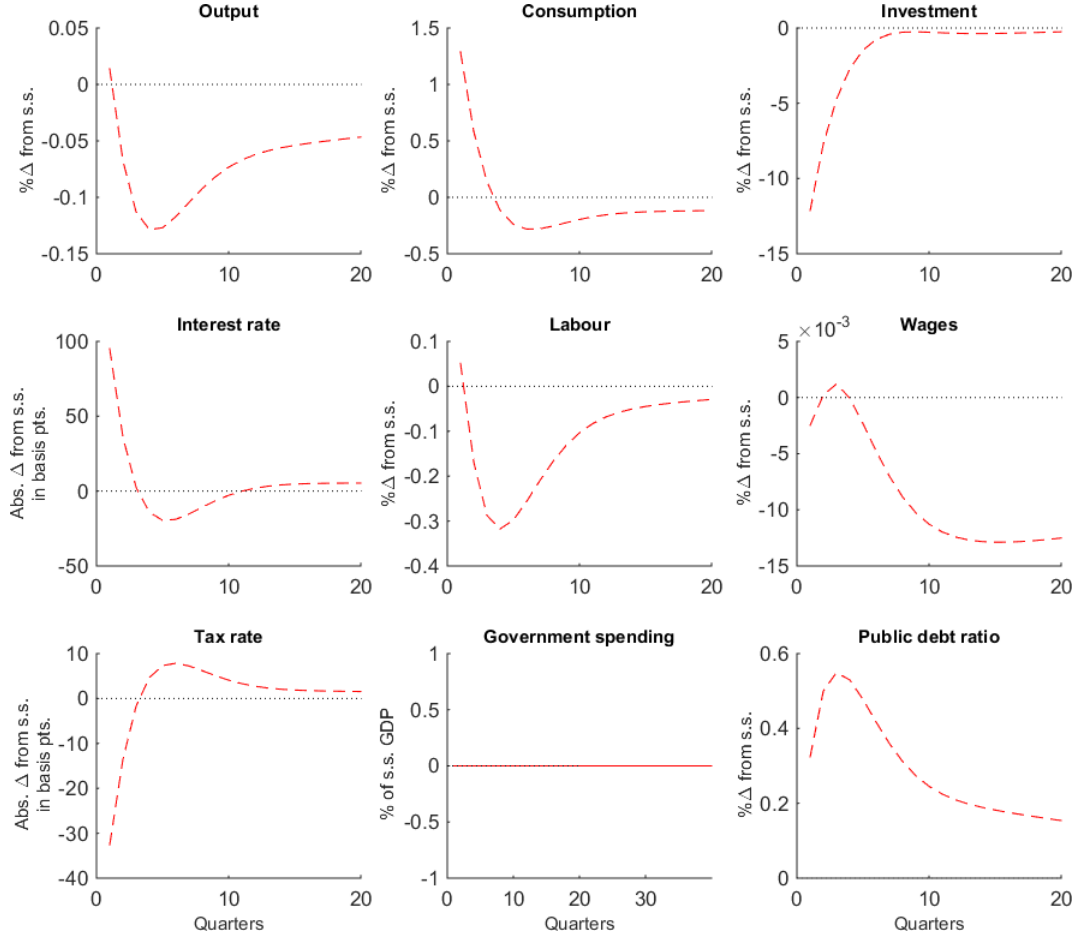
A positive shock on the permanent component of government expenditure generates a smaller multiplier under perfect information in the first quarter. Even though in the short run the imperfect information multiplier is larger, in the long run it becomes smaller than the perfect information multiplier, as agents learn about the true nature of the shock and perceive the accurate financing costs of fiscal policy.

1.3.4 Noise shocks

In fiscal policy there are some circumstances where imperfectly informed agents underestimate the costs of policies. On the one hand, there is the example of fiscal illusion (*e.g.*, Alesina and Perotti, 2008) where taxpayers are argued to overestimate the benefits of public spending and to underestimate the costs of taxation due to imperfect information or technical complexity, leading to persistent deficits. On the other hand, the literature on fiscal transparency (*e.g.*, Kopits and Craig, 1998) acknowledges cases such as the complexity of the government budget and the use of creative accounting to disguise certain outcomes from the public that underestimates the effects of non-efficient policies.¹² The announcement of fiscal policies that are embedded with “noise” in a similar fashion as the examples above may generate expectational errors in the agents’ beliefs regarding the evolution of fiscal tools.

¹²A recent example of the effects of fiscal profligacy when economic agents do not account for its costs was the sovereign debt crisis in Europe after the 2008 global crisis.

Figure 1.4: Impulse responses to a 1SE negative shock in the noisy fiscal signal



Note: $\phi_G = 0.50$; $\phi_D = 0.10$; $\nu = 1$.

The focus now is on the effects of a noise shock, which is non-fundamental in the sense that it is a pure shock to expectations and does not affect government expenditure. In order to capture, to some extent, the underestimation of tax costs described above, the effects of a negative noise shock are analyzed. Figure 1.4 shows the dynamics of the economy after a negative noise shock that temporarily makes agents to believe that the permanent government expenditure has decreased. This is reflected into a decrease in the expected tax rate – thus, a perception of a temporary positive wealth effect –, leading consumption, output and labor supply to increase and investment to decline. The rise in consumption implies lower savings, thus capital accumulation and investment drops temporarily, originating a rise in the interest rate. The fall of the perceived tax rate motivates the rise of labor supply and, consequently, the fall in wages. In public finances, given that government expenditure remains constant, the expected public debt rises to accommodate the fall of the expected tax rate.

An interesting result is the positive comovement of output, consumption and hours worked following a negative noise shock. Since agents face a temporary underestimated tax rate, this “illusion” triggers temporary positive wealth effects.

The dynamics of expectations may shed some light on the non-Keynesian effects of fiscal consolidations, in the sense that a perceived fiscal contraction leads to the expansion of the economy (*e.g.*, Bertola and Drazen, 1993; and Perotti, 1999). Nonetheless, in the fiscal consolidation scenario the positive results are originated by expectations due to an anticipation effect and in our case the results are generated by noise about, for instance, a consolidation that will never be effective.

1.3.5 Sensibility analysis

The magnitude of the effects of government expenditure shocks depends on the degree of imperfect information.¹³ It also depends on the relative magnitude of the feedback parameters on the fiscal rule. Figures 1.5 and 1.6 exhibit alternative responses of macroeconomic variables to a temporary and permanent shock in government expenditure, respectively, using different calibration values for ϕ_G and ϕ_D . In sum, the higher ϕ_G and the lower ϕ_D , the larger will be the effects of distortionary taxation in the model. In contrast, the lower ϕ_G and the higher ϕ_D , the smaller will be the effects of distortionary taxation, as well as the effects of imperfect information.

Figures 1.8 and 1.9 (in Appendix) plot the impulse response functions of a 1% GDP shock on the temporary and permanent components of government expenditure, respectively, for several scenarios of imperfect information. Comparing to the benchmark model where $\nu = 1$, when agents face a higher degree of imperfect information, $\nu < 1$, a positive shock in the temporary expenditure component makes: (i) the effects of distortionary taxes stronger – smaller output multiplier, deeper negative effects on consumption, smaller crowding out effect on investment and higher labor supply; and (ii) perceived and expected tax rates higher and government deficits smaller. Moreover, a positive shock in the permanent expenditure component: (i) is underestimated, leaving space for smaller short-run negative effects on consumption, smaller positive effects on labor supply and increased crowding out effect on investment, and thus higher negative effects on output; and (ii) intensifies the underestimation of tax rates in the short-run, hence amplifies fiscal deficits which demands more debt.

¹³Note that when $\sigma_s^2 = 0$ the model corresponds to the perfect information scenario.

Table 1.2: Sensibility Analysis to φ_n and ν : impact output multiplier (%)

φ_n	0	2	6	10
<i>Temporary shock</i>				
ν				
3	1.0059	0.3644	0.1538	0.0967
1	0.9537	0.3687	0.1610	0.1023
0.1	0.8564	0.3768	0.1743	0.1129
<i>Permanent shock</i>				
3	0.6597	0.3931	0.2013	0.1341
1	0.8240	0.3795	0.1787	0.1164
0.1	0.8522	0.3771	0.1749	0.1133

When agents face a smaller degree of imperfect information, $\nu > 1$, the higher is the signal-to-noise ratio and results converge to those under perfect information.

Finally, Table 1.2 summarizes the sensibility analyses of the impact output multiplier to alternative values of the elasticity of leisure relative to real wage (φ_n) and different degrees of imperfect information. For $\varphi_n \neq 0$ the impact multiplier is decreasing in φ_n and: decreasing in ν for temporary shocks; and increasing in ν for permanent shocks. When $\varphi_n = 0$, the opposite is observed, the impact multiplier is increasing in ν for temporary shocks and decreasing for permanent shocks.

1.4 Conclusion

This paper studies the effects of fiscal policy when agents are imperfectly informed about the true composition of government expenditure. In such misreading of fiscal policy, agents need to learn about the nature of fiscal shocks. An RBC model with distortionary taxation and government debt is developed, where agents learn about fiscal policies using a specific Kalman filter. Applying Brunner et al. (1980) and Kydland and Prescott (1982) type of model to fiscal policy, government expenditure was theoretically divided into temporary and permanent components, similarly as Barro (1981) and Aiyagari et al. (1992).

The results obtained through numerical simulations suggest that under imperfect information: (i) the distortionary effects of taxes are worse when the government expenditure shock is temporary, due to the probability attributed by agents of the shock being permanent; (ii) in turn, the negative wealth effects of a permanent positive shock on government expenditure are not immediately identified, leading

to higher short run effects on output, consumption and labor supply, and also to higher deficits.

When compared with the scenario where agents have perfect information, the multiplier of a shock in the temporary component of government expenditure under imperfect information is smaller in the short run and larger, but negative, in the long run. Conversely, the multiplier of a shock in the permanent component of government expenditure is larger in the short run and smaller in the long run.

The larger the degree of imperfect information, the worse is the perceived negative wealth effect of a positive shock either on the temporary or the permanent component of government expenditure. Stressing the importance of information transparency in fiscal policy outcomes may also motivate for the role of fiscal councils in disseminating public information and increasing the transparency of the budget and of fiscal performance (*e.g.*, Debrun et al., 2009). A key contribution of this paper is the study of the role of expectations in fiscal policy using a “noise” channel. A negative fiscal noise shock was simulated, where taxpayers temporarily believe, that the permanent component of government expenditure falls. Since this is a pure shock to expectations, it does not affect government expenditure. It is instead reflected into a decrease of the expected tax rate and into an increase of the expected public debt, being perceived as a temporary positive wealth effect and hence leading consumption, output and labor supply to increase while investment declines. This shock in expectations generates comovement of output, consumption and hours worked. These results may contribute to a possible explanation for the expectational effects of fiscal policy. Alternative to anticipation effects, the noise effects tested in this paper may also support evidence, although through a different channel, on the non-Keynesian effects of fiscal consolidations studied, for instance, by Bertola and Drazen (1993). Further extensions of this paper include the estimation of the model using Bayesian econometric techniques.

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Appendix

1.A Kalman Filter

Define the system matrices

$$\mathbf{C} \equiv \begin{bmatrix} 1 + \rho & -\rho & 0 \\ 1 & 0 & 0 \\ 0 & 0 & \rho \end{bmatrix}, \mathbf{D} \equiv \begin{bmatrix} 1 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}.$$

and

$$\mathbf{\Sigma}_1 \equiv \begin{bmatrix} \sigma_P^2 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \sigma_T^2 \end{bmatrix}, \mathbf{\Sigma}_2 \equiv \begin{bmatrix} 0 & 0 \\ 0 & \sigma_s^2 \end{bmatrix}.$$

Both presented in the compact form, the measurement equation is given by

$$(g_t, s_t)' = \mathbf{D} \cdot \xi_t + (0, \varepsilon_t^s)',$$

and the transition equation, which summarizes the evolution of unobserved variables, is

$$\xi_t = \mathbf{C} \cdot \xi_{t-1} + z + (\varepsilon_t^P, 0, \varepsilon_t^T)'.$$

Assume that $\mathbf{e}_t = (g_{t|t}^P, g_{t-1|t}^P, g_{t|t}^T)$ is the optimal estimator of $\xi_t = (g_t^P, g_{t-1}^P, g_t^T)$ based on information set, I_t , then

$$\mathbf{e}_t \equiv E[\xi_t | I_t].$$

The covariance matrix of the estimation error is given by $\mathbf{P}_t$,

$$\mathbf{P}_t \equiv E[(\xi_t - \mathbf{e}_t)(\xi_t - \mathbf{e}_t)'].$$

The steady state error covariance matrix can be calculated as a solution to the following algebraic Riccati equation

$$\mathbf{P} = \mathbf{C} \left[\mathbf{P} - \mathbf{P}\mathbf{D}' (\mathbf{D}\mathbf{P}\mathbf{D}' + \mathbf{\Sigma}_2)^{-1} \mathbf{D}\mathbf{P} \right] \mathbf{C}' + \mathbf{\Sigma}_1 .$$

Using I_{t-1} and the transition equation,

$$\mathbf{e}_{t|t-1} = \mathbf{C} \cdot \mathbf{e}_{t-1} .$$

The updating rule sets the posteriors $\mathbf{e}_t$ to be a convex combination of prior beliefs and the new signal g_t

$$\mathbf{e}_t = \mathbf{A} \cdot \mathbf{e}_{t|t-1} + \mathbf{B} \cdot \begin{bmatrix} g_t \\ s_t \end{bmatrix} ,$$

where matrix $\mathbf{A}$ is given by

$$\mathbf{A} = (\mathbf{I} - \mathbf{B}\mathbf{D}) \mathbf{C} ,$$

and contains the information by how much the prior beliefs are weighted in the current beliefs; $\mathbf{I}$ is an identity matrix of size 3×3 ; and matrix $\mathbf{B}$

$$\mathbf{B} = \mathbf{P}\mathbf{D}' (\mathbf{D}\mathbf{P}\mathbf{D}' + \mathbf{\Sigma}_2)^{-1} ,$$

is the Kalman gain and its coefficients indicate how much agents weight the respective observables.

1.B Sensibility analysis for the fiscal rule

Figure 1.5: Sensibility analysis for different values assigned to parameters ϕ_G and ϕ_D , given a 1% GDP shock in temporary government expenditure

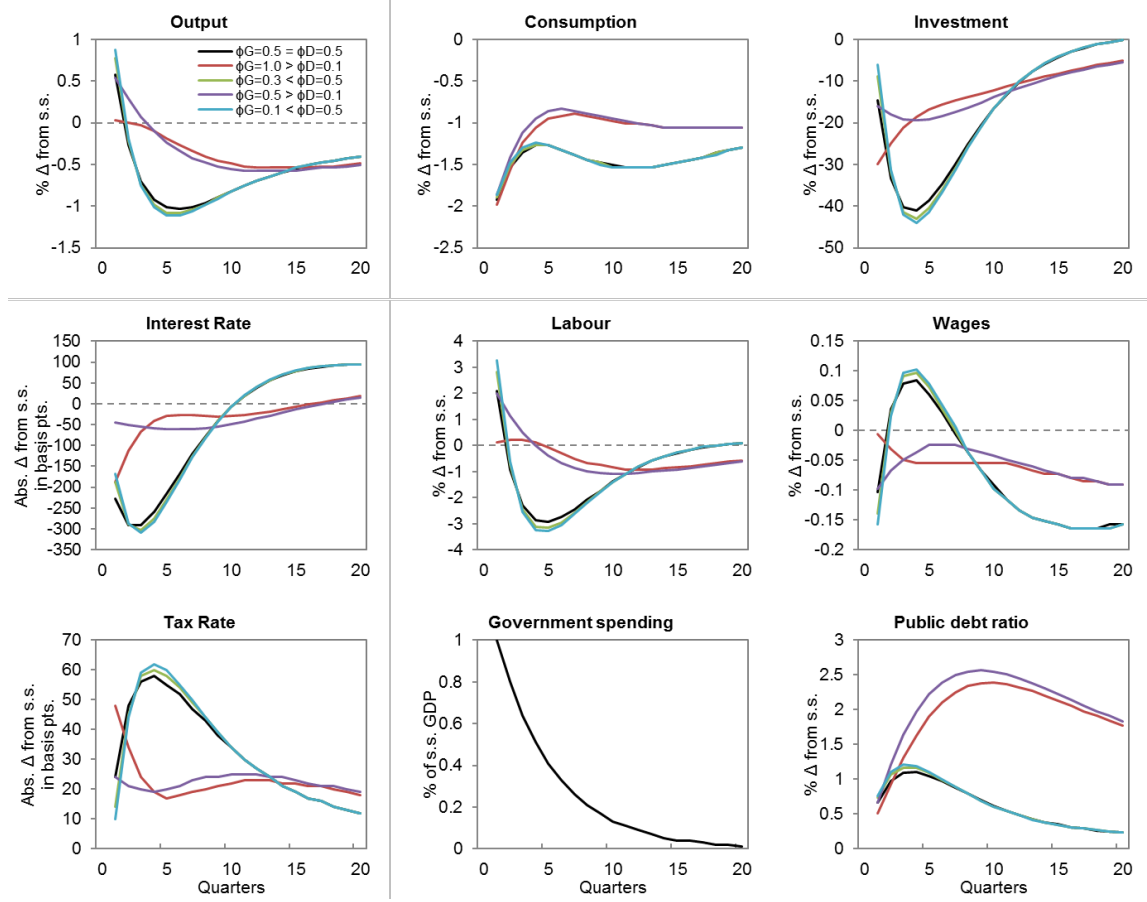


Figure 1.6: Sensibility analysis for different values assigned to parameters ϕ_G and ϕ_D , given a 1% GDP shock in permanent government expenditure

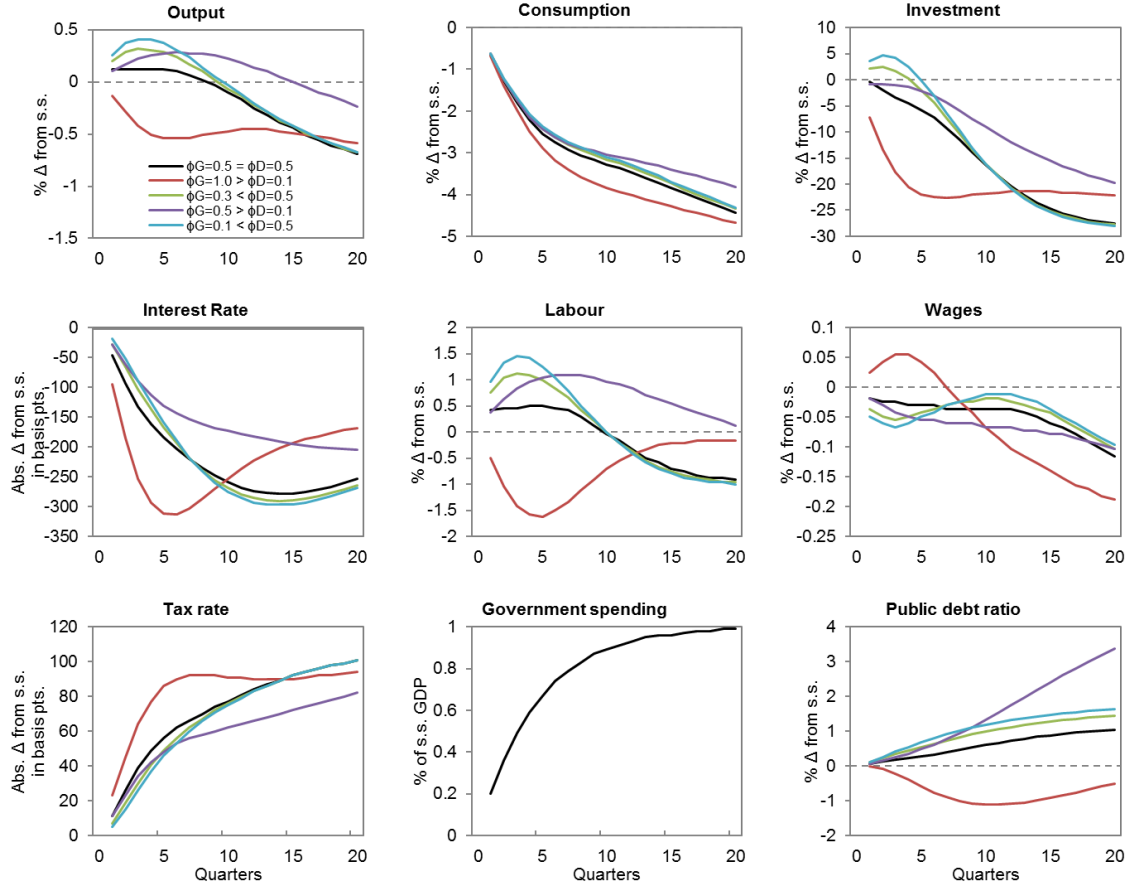
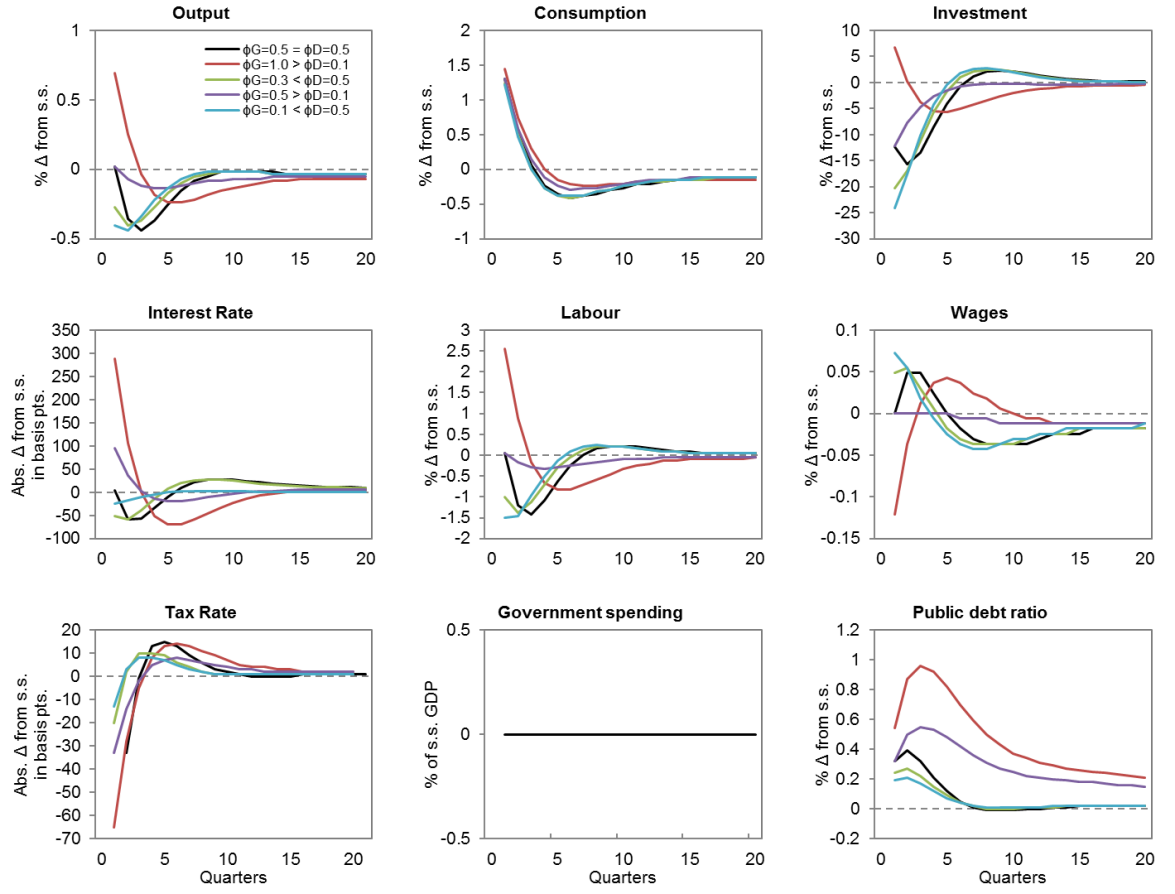


Figure 1.7: Sensibility analysis for different values assigned to parameters ϕ_G and ϕ_D , given a 1SE negative shock in the noisy signal of permanent government expenditure



1.C Sensibility analysis for imperfect information

Figure 1.8: Sensibility analysis for different degrees of imperfect information, given a 1% GDP shock in temporary government expenditure

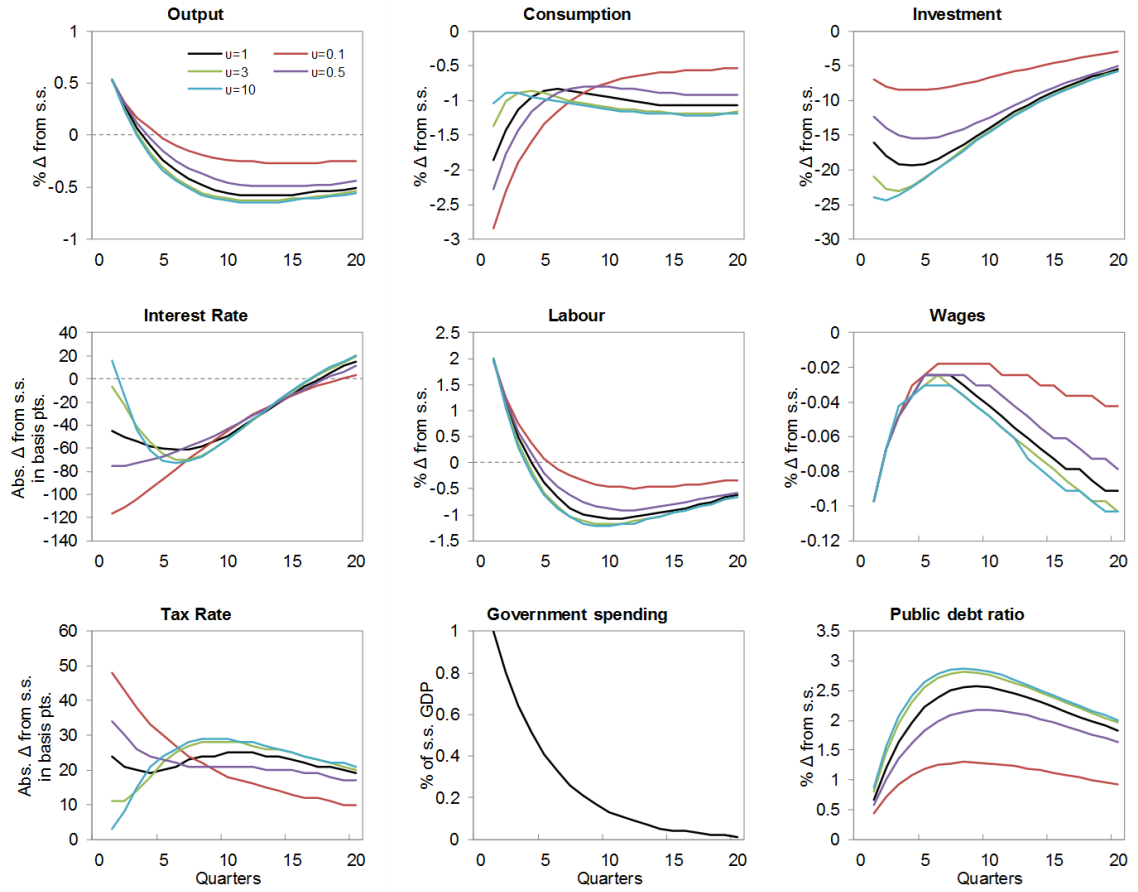


Figure 1.9: Sensibility analysis for different degrees of imperfect information, given a 1% GDP shock in permanent government expenditure

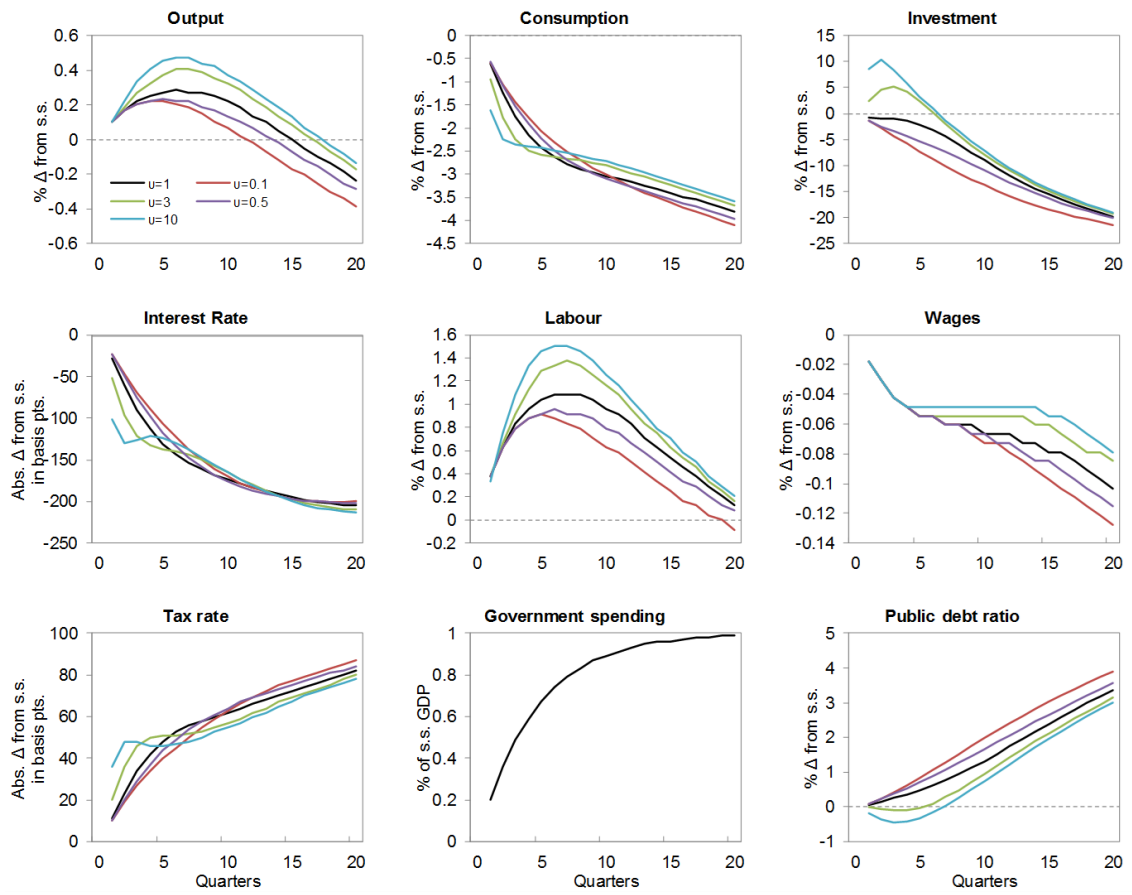
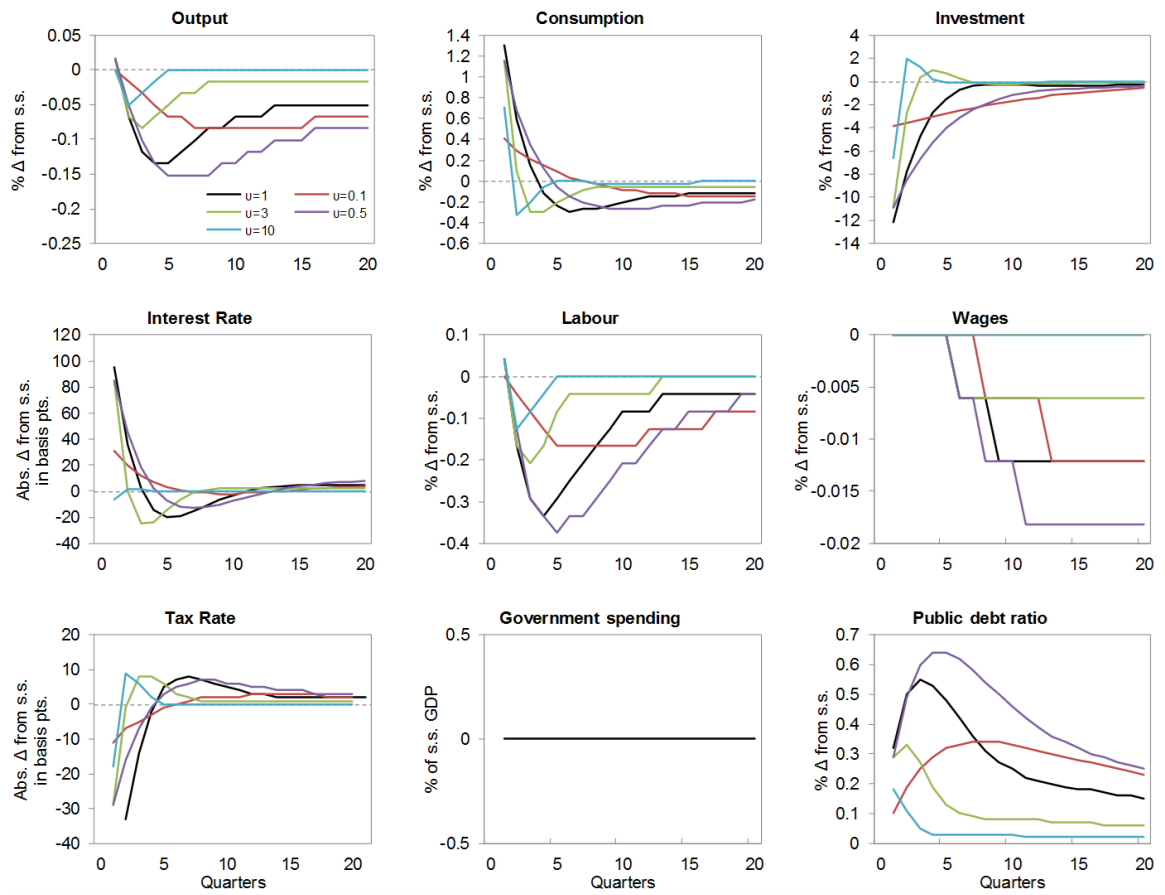


Figure 1.10: Sensibility analysis for different degrees of imperfect information, given a 1SE negative shock in the noisy signal of permanent government expenditure



Chapter 2

Financial frictions, public debt financing and uncertain fiscal rigidity

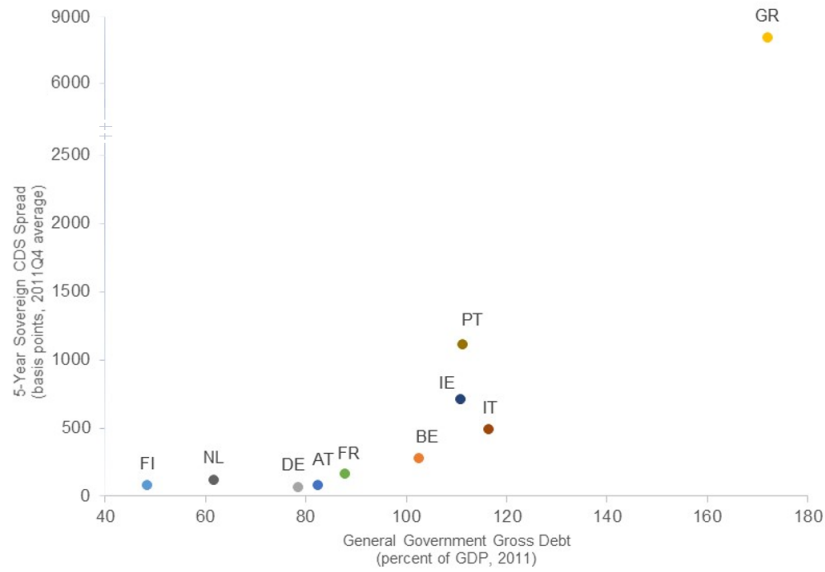
2.1 Introduction

Countries are frequently penalized with risk premia when their macroeconomic fundamentals and fiscal policies raise concerns about the riskiness of government debt. During the period 2009-2011 Spain debt rating was downgraded from AAA to AA, Ireland from AAA to BBB+, Portugal from AA to BBB-, and Greece from A to CC (Bi, 2012), while the markets assisted to the deteriorating of public finances in these countries: the general government gross debt in Spain raised 16.8 percentage points (p.p.) to 69.5% of GDP, Ireland had a debt hike of 49.3 p.p. to 110.9% of GDP, Portugal raised debt 27.8 p.p. to 111.4% of output, and Greece's ratio grew by 45.3 p.p. to 172.1% of GDP. The fundamentals that drive the debt dynamics lead to distinct market reaction to riskiness. Sovereign yield spreads began to widen in euro area soon after the beginning of the global financial crisis in 2007-2008 (Von Hagen, 2013).¹ As the financial crisis evolved, yield spreads first rose in response to the increased degree of risk aversion in international financial markets and then became much more responsive to indicators of fiscal sustainability such as debt, deficit ratio and policy announcements. Figure 2.1 depicts the relation of debt and risk premia for a selection of euro area countries. It shows that CDS spreads are higher for high levels of debt-to-GDP ratios, but it appears to rise disproportionately as the ratio rises.

In most of the European countries that suffered the sovereign debt crisis, the deficit financed fiscal response to counteract the fact that the 2007-2008 global fi-

¹Even before the crisis started, yield spreads reacted to differences in fiscal performance among countries (*e.g.*, Von Hagen et al., 2011; and Bernoth et al., 2012).

Figure 2.1: Sovereign risk premia and debt in 2011



Source: Thomson Reuters and AMECO

nancial crisis was undertaken by structural rather than cyclical changes (Von Hagen, 2013). Most of these countries exhibited significantly stronger increases in social benefits, government final consumption, and in compensations of public sector employees than the euro-area average – spending categories that are more rigid and generally difficult to reverse and, therefore, translate into longer-lasting budgetary effects. Following Von Hagen (2013), Table 2.1 shows a difference-in-difference analysis of fiscal adjustments for Spain, Ireland, Portugal, Greece and Italy. Comparing to euro-area average, boldface numbers highlight country-specific differences in excess of one cross-section standard deviation among the euro-area countries other than the crisis countries (see Table 2.5 in Appendix).

The data reveals that, for these crisis countries, during the 2007-2008 global financial recession, there is a remarkable large share of the change in structural balance in the overall budget balance, which indicates that most of the fiscal adjustment to counteract the recession was undertaken by structural rather than cyclical measures. Furthermore, crisis countries seem to have used relatively more sticky fiscal policy tools, particularly in the public expenditure side, than the rest of the group.

Table 2.1: European debt crisis: changes in selected variables (% of GDP)

Variable	country	2007-08	2009-11	country	2007-08	2009-11
Real gdp growth		-2.3	1.2		-3.6	-4.8
Total expenditures		0.8	-0.2		3.8	0.2
<i>social benefits</i>		<i>0.5</i>	<i>0.6</i>		<i>1.5</i>	<i>2.0</i>
<i>compensations</i>	PT	<i>0.0</i>	<i>-1.2</i>	GR	<i>0.5</i>	<i>-0.5</i>
<i>interest</i>		<i>0.2</i>	<i>1.3</i>		<i>0.3</i>	<i>2.2</i>
Primary balance		-0.6	3.8		-3.2	7.1
Share of struct. balance		104.4	72.0		61.7	229.1
Debt ratio		3.2	27.8		6.3	45.4
Real gdp growth		-2.7	2.6		-2.5	6.1
Total expenditures		2.1	0.0		1.0	-1.8
<i>social benefits</i>		<i>0.8</i>	<i>1.0</i>		<i>0.6</i>	<i>0.1</i>
<i>compensations</i>	ES	<i>0.6</i>	<i>-0.2</i>	IT	<i>0.2</i>	<i>-0.6</i>
<i>interest</i>		<i>0.0</i>	<i>0.8</i>		<i>0.2</i>	<i>0.3</i>
Primary balance		-6.4	2.1		-1.0	1.8
Share of struct. balance		79.9	156.7		44.9	23.6
Debt ratio		3.9	16.8		2.6	4.0
Real gdp growth		-2.5	5.9		-8.2	4.5
Total expenditures		1.3	-1.5		6.0	-1.1
<i>social benefits</i>		<i>0.3</i>	<i>-0.3</i>		<i>1.9</i>	<i>-0.5</i>
<i>compensations</i>	EA*	<i>0.2</i>	<i>-0.4</i>	IE	<i>1.2</i>	<i>-1.0</i>
<i>interest</i>		<i>0.1</i>	<i>0.2</i>		<i>0.3</i>	<i>1.3</i>
Primary balance		-1.4	2.2		-7.0	2.5
Share of struct. balance		-39.4	60.9		49.6	87.4
Debt ratio		3.8	8.5		18.5	47.9

Sources: AMECO - European Commission and OECD statistics for the structural balance in the years 2007-2008

Notes: * euro area definition with 12 countries (2001); bold figures denote deviations from euro-area(12) average in excess of one cross-section standard deviation among the non-crisis countries (see Table 2.5 in Appendix)

The increase in rigid public spending to fight the crisis pushed the economies to their fiscal limits and as economic agents started to look to indicators of fiscal sustainability, the higher the uncertainty about fiscal policies that could translate into longer-lasting budgetary effects the more penalized would be the country by international markets. Under this hypothesis the debt sovereign crisis is the result of a policy that increases highly persistent spending budget components to fight a severe recession. It becomes a crisis because lenders anticipate the government's inability to reverse the increase later on. Nonetheless, the difficulty to distinguish

permanent from temporary changes in fiscal policy is a major source of fiscal policy uncertainty (*e.g.*, Baker et al., 2016; Hollmayr and Matthes, 2015), which is expected to have significant impact on the markets assessment of a country's fiscal stance. Moreover, the literature concludes that uncertainty about permanent changes in policy has important effects on economic activity (*e.g.*, Bi et al., 2013). It is therefore important to understand how expectations about the nature of fiscal policy (persistent or temporary) interact with sovereign debt risk in order to discuss what kind of policies are better suitable to stimulate an economy or to avoid a deeper crisis. A common framework for such analysis is through the use of a dynamic stochastic general equilibrium (DSGE) framework, which is at the core of this paper.

In order to capture the above mentioned dynamics, a DSGE model is build that incorporates balance sheet constrained financial intermediaries which supply loans both to firms and to the government, this way holding sovereign debt in their balance sheets. It allows to explicitly introduce a sovereign risk premium to assess the importance of the transmission of fiscal policy in this context. As highlighted by numerous examples in the literature (*e.g.*, Corsetti et al., 2013; van der Kwaak and van Wijnbergen, 2014; Kirchner and van Wijnbergen, 2016; Bocola, 2016), at the end of 2009 domestic government bond holdings in the euro-area peripheral countries such as Greece, Italy, Portugal and Spain was equivalent to 93 percent of banks' total equity, leading this way to a severe disruption of financial intermediation and a substantial increase in the borrowing costs of firms during the 2009-2011 sovereign debt crisis. In this paper, the government issues one period non-state-contingent bonds to banks and collects taxes from households in a lump-sum manner in order to finance expenditures and repay existing debt. Public spending is composed by a persistent component, mimicking the more rigid budgetary spending components, and by a transitory component. Following, among others, Bi (2012) and Bi and Leeper (2013), government faces a fiscal limit. Bi and Leeper (2013) show that the risk premium turn out to be very sensitive to changes in the persistence of the fiscal transfer regime – increasing the persistence of fiscal transfers even slightly results in a significant increase in the risk premium and pulls the fiscal limit closer to the current debt ratio. In this paper the fiscal limit is given by a debt limit, modeled as a function of the rigid expenditure component. Default occurs whenever the ratio of persistent spending to total revenues is close to one. The novelty of this model is the introduction of imperfect information on the nature (persistent or temporary) of fiscal policy in an otherwise standard macroeconomic model with financial frictions. Agents behavior is fully rational given their information sets and form expectations about the future government spending, hence future government financing costs,

based on their observations of current total government spending and observing a noisy signal about the persistent spending component.

One can identify three factors that contribute to the problem of uncertainty while implementing fiscal policies. First, it results from a political constraint of the government (Von Hagen, 2013), as political opposition from groups of voters and their representatives against cuts in transfer programs such as pensions or welfare payments and reductions in public employment generates persistence in government expenditures. Second, it can result from rules included in legislation. It is common that a country's legal framework builds up tight defenses against cuts in civil servants' wages and pensions and welfare programs. Typically this factor is highly correlated with the first. Portugal has an interesting example during the consolidation period after the debt crisis, when in April 2013 Portugal's Constitutional Court declared unconstitutional a further extension of the wage cut already applied to civil servants. Investors are reactive to uncertainty, as Fitch expressed in a document published that year:

“In blocking a plan to suspend a monthly salary payment to state workers, the ruling could be interpreted as a saying that all public spending cuts that affect civil servants are unconstitutional. This raises concerns about how the government would implement further cuts arising from its planned comprehensive spending review (...) If that interpretation is correct, the ruling represents a setback to future fiscal adjustment efforts in Portugal. This is a greater concern than its immediate impact.”²

The third factor is associated with measurement issues. To identify the permanent component of expenditure, on the one hand, one can rely on the structural expenditure approach but then we face the uncertainty of the estimates associated to the estimation and revisions of potential output. On the other hand, focusing on the disaggregation of expenditure by type, where social expenditures, age-related spending, and wages are typically associated with a greater rigidity, is also a misleading approach, since the expenditure level is the result of both transitory and permanent policies.

The key results of this paper suggest that imperfect information about the true nature of government spending amplifies the impact multiplier of persistent spending policies as agents do not fully anticipate the associated fiscal costs so the rise in expected interest rates and credit spreads, through the associated tightening of

²Citation from the above original article appeared as a post on the Fitch Wire credit market commentary page on 08 April 2013 (<https://www.fitchratings.com/site/pr/787792>)

bank balance sheet constraints and intermediary balance sheet adjustments, are limited, as well as the drop in debt-limit and the rise in probability of default. As a consequence of the smaller rise in borrowing costs, the demand for capital, and thus investment, is less crowded out and output expands further. Although the impact multiplier is higher than under perfect information, as agents learn about the true nature of the spending shock, the expectations about persistent debt financed deficits are adjusted and reflected in credit spreads leading to a worst cumulative output response. Cumulative output responses to persistent government spending shocks are lower with imperfect information than with perfect information. Furthermore, the results suggest that, for any degree of information, less persistent spending policies – spending policies that imply less taxation in the future – are more efficient in counteracting a crisis as they imply lower output losses. Exploring a pure expectation channel through the consideration of a fiscal noise shock, it is also shown that, for this particular framework, non-fundamental fiscal shocks have business cycle effects and are able to change sovereign risk premia, due to the interaction of banks’ balance sheet adjustments, leverage constraints and the expectation of future debt financed fiscal deficits.

The reminder of this paper is the following: section 2 outlines the model and characterizes the fiscal limit and sovereign default definitions used in this paper; section 3 parameterizes the model and presents three distinct exercises based on the simulation results with impulse responses of key economic variables – the effects in the economy of the composition of government spending policies when information is imperfect, the business cycle consequences of a noisy fiscal shock, and how different spending policies (persistent/transitory) are effective in counteracting a financial crisis under imperfect information. Section 4 concludes.

2.2 The model

This section provides a concise overview of the model which builds on the New Keynesian framework with financial intermediation and public debt, similar to Gertler et al. (2013), Bocola (2016) and Kirchner and van Wijnbergen (2016), where banks assume a role in deficit financing. The core elements are relatively standard. In addition, the imperfect information setup for fiscal policy and the solution method information model are debated.

The economy is populated by households, final good producers, capital good producers and policy authorities. Each household is composed of two types of members: workers and bankers. Workers supply labor to final good firms. Bankers

borrow from capital markets in order to invest in government bonds and in claims of firms. Firms rent labor from workers and buy capital from capital good producers in order to produce a homogeneous good. Their capital expenses are financed by the bankers. The monetary authority sets the risk-free nominal interest rate. The government issues bonds and taxes households in order to finance government spending.

2.2.1 Households

There is a continuum of identical households of measure unity. Each household consumes, saves and supplies labor. Households save by lending funds to competitive financial intermediaries that they do not own. Following Gertler and Karadi (2011), within each household there is a fraction $1 - \varsigma$ of workers that supply labor to firms and a fraction ς of bankers that manage financial intermediaries (banks). There is perfect consumption insurance within the family. Over time an individual can switch between the two occupations. In order to exclude self-financing equilibria bankers have finite life times. In particular, a banker this period stays banker next period with probability θ , which is independent of history (*i.e.*, of how long the person has been a banker). The average survival time for a banker in any given period is thus $1/(1-\theta)$. If the intermediary exits, the respective bankers become workers and transfer all retained capital back to the household. Thus, every period $(1 - \theta)\varsigma$ bankers become workers, and a similar number of workers randomly become bankers, keeping the relative proportion of each type fixed.

Let c_t be consumption and h_t household labor supply. Then the representative household in period t maximizes the expected discounted utility given by

$$U_t = E_t \sum_{i=0}^{\infty} \beta^i \left[\log(c_{t+i} - \vartheta c_{t+i-1}) - \frac{h_{t+i}^{1+\varphi}}{1+\varphi} \right], \quad (2.1)$$

with $0 < \beta < 1$, $0 < \vartheta < 1$ and $\varphi > 0$. As in Christiano et al. (2005) we allow for habit formation to capture consumption dynamics. The household budget constraint is given by

$$c_t + d_t + \tau_t \leq w_t h_t + (1 + r_t^d) d_{t-1} + \Pi_t, \quad (2.2)$$

where w_t denotes real wage, d_{t-1} are the beginning-of-period deposits, r_t^d is the net real interest rates on deposits, τ_t are lump-sum taxes, and Π_t are payouts from ownership of both non-financial and financial firms, net of transfers given to household member that becomes banker at time t .

2.2.2 Financial intermediaries

Financial intermediaries, investment and commercial banks, lend funds obtained from households to non-financial firms and to government. They are competitive and located on a continuum indexed by $j \in [0, 1]$. Each bank intermediary chooses its asset holdings to maximize the expected transfer to household that owns the respective bank, where a moral hazard problem constrains the bank's ability to obtain external funds as in Gertler and Karadi (2011). The moral hazard problem gives rise to an endogenous leverage constraint: for given capital, total assets have to be consistent with that leverage constraint if any external funding is to be raised.

Total assets of intermediary j at the end of period t are given by

$$p_{j,t} = q_t s_{j,t}^k + s_{j,t}^b, \quad (2.3)$$

where $s_{j,t}^k$ denote claims on intermediate goods firm by bank j that have the relative price q_t and that pay a net real return r_{t+1}^k at the beginning of period $t + 1$, and $s_{j,t}^b$ are bank j 's government bond holdings that pay a net real return r_{t+1}^b at the beginning of period $t + 1$. The balance sheet of intermediary j is then given by

$$p_{j,t} = d_{j,t} + n_{j,t}, \quad (2.4)$$

where $d_{j,t}$ denote deposits the intermediary j obtains from households and $n_{j,t}$ is the amount of wealth – or net worth – that a banker j has at the end of period t . Net worth evolves over time as the difference between earnings on assets and interest payments on liabilities

$$\begin{aligned} n_{j,t} &= (1 + r_{t+1}^k) q_t s_{j,t}^k + (1 + r_{t+1}^b) s_{j,t}^b - (1 + r_{t+1}^d) d_{j,t} \\ &= (r_{t+1}^p - r_{t+1}^d) p_{j,t} + (1 + r_{t+1}^d) d_{j,t}, \end{aligned} \quad (2.5)$$

where r_{t+1}^p is the net ex-post real portfolio return which, after defining the portfolio weights $\omega_{j,t} = q_t s_{j,t}^k / p_{j,t}$ and $1 - \omega_{j,t} = s_{j,t}^b / p_{j,t}$, is given by

$$1 + r_t^p = (1 + r_t^k) \omega_{j,t-1} + (1 + r_t^b) (1 - \omega_{j,t-1}). \quad (2.6)$$

At the beginning of period $t + 1$, after financial payouts have been made, an individual bank intermediary continues operating with probability θ and exits with probability $1 - \theta$, in which case it transfers its retained capital to its household. The bank manager's objective in period t is therefore to maximize the expected value of discounted terminal wealth

$$V_{j,t} = E_t \sum_{i=0}^{\infty} (1 - \theta) \theta^i \beta^{i+1} \Lambda_{t,t+1+i} n_{j,t+1+i}, \quad (2.7)$$

by deciding on size and allocation of his asset portfolio given his initial net worth $n_{j,t}$. Following Gertler and Karadi (2011), we assume that a costly enforcement problem constrains the ability of banks to obtain funds from depositors. At the beginning of the period t , the banker can choose to divert a fraction λ^* of total assets it holds, $\lambda^* p_{j,t}$, and transfer the proceeds to the household of which he or she is a member. The cost to the banker is that the depositors can force the intermediary into bankruptcy and recover the remaining fraction of assets, $(1 - \lambda^*) p_{j,t}$. However, it is too costly for the depositors to recover the funds that the banker diverted. Accordingly, for depositors to be willing to supply funds to the banker, the following incentive constraint must be satisfied:

$$V_{j,t} \geq \lambda^* p_{j,t}. \quad (2.8)$$

The banker's maximization problem is to choose $s_{j,t}^k$ and $s_{j,t}^b$, to maximize (2.7) subject to (2.3), (2.5), and (2.8). The solution to the problem follows closely Gertler and Karadi (2011) and it can be conjectured as

$$V_{j,t} = v_t^k q_t s_{j,t}^k + v_t^b s_{j,t}^b + \eta_t n_{j,t},$$

where

$$\begin{aligned} v_t^k &= E_t \beta \Lambda_{t,t+1} \left\{ (1 - \theta) (r_{t+1}^k - r_{t+1}^d) + \theta \frac{q_{t+1} s_{j,t+1}^k}{q_t s_{j,t}^k} v_{t+1}^k \right\}, \\ v_t^b &= E_t \beta \Lambda_{t,t+1} \left\{ (1 - \theta) (r_{t+1}^b - r_{t+1}^d) + \theta \frac{s_{j,t+1}^b}{s_{j,t}^b} v_{t+1}^b \right\}, \\ \eta_t &= E_t \beta \Lambda_{t,t+1} \left\{ (1 - \theta) (1 + r_{t+1}^d) + \theta \frac{\eta_{j,t+1}}{\eta_{j,t}} \eta_{t+1} \right\}, \end{aligned}$$

The variable v_t^k is the expected discounted marginal gain of an additional unit of claims on intermediate goods firms, the variable v_t^b is the expected discounted marginal gain of another unit of government bonds, and the variable η_t is the expected discounted marginal gain associated with an additional unit of net worth. From the first-order conditions the relation $v_t^b = v_t^k = v_t$ is obtained, which combined with the leverage constraint yields:

$$q_t s_{j,t}^k + s_{j,t}^b = \phi_t n_{j,t} \text{ , } \phi_t = \frac{\eta_t}{\lambda^* - v_t}$$

A key component of the solution is the leverage ratio ϕ_t which denotes the bank's leverage ratio of assets over net worth and limits the bank's leverage ratio to the point where banker's incentive to cheat is exactly balanced by the cost.

2.2.3 Firms

The production side of the economy is characterized by four types of firms that are all owned by the households: (i) a continuum of intermediate goods producers indexed by $i \in [0, 1]$ borrowing from the financial intermediary to purchase the capital necessary for production of differentiated goods $y_{i,t}$; (ii) a continuum of monopolistically competitive retail firms indexed by $f \in [0, 1]$ that re-package intermediate goods $y_{i,t}$ into retail goods $y_{f,t}$ to sell to final goods producers; (iii) a continuum of perfectly competitive final goods producers that combine the intermediate goods into a single good y_t to sell to the households, the government and the capital producer; and (iv) a continuum of competitive capital goods producer that repair depreciated capital and build new productive capital that is sold to intermediary goods producer.

Final goods firms

A representative final goods firm buys the intermediate goods provided by the retail firms to construct consumption aggregates, which have the CES form,

$$y_t^{\frac{\epsilon-1}{\epsilon}} = \int_0^1 y_{f,t}^{\frac{\epsilon-1}{\epsilon}} df \text{ ,}$$

where ϵ is the elasticity of substitution among intermediate goods. Cost minimization for final goods firms, taking the retail prices $P_{f,t}$ and the final goods price P_t as given, results in the demand curve for intermediate good f ,

$$y_{f,t} = \left(\frac{P_{f,t}}{P_t} \right)^{-\epsilon} y_t \text{ ,}$$

and an expression for the aggregate price level

$$P_t^{1-\epsilon} = \int_0^1 P_{f,t}^{1-\epsilon} df \text{ .}$$

Retail firms

Retail firms buy intermediate goods $y_{i,t}$ at the market price P_t^m and re-package those goods into retail goods $y_{f,t}$ that are sold in a monopolistically competitive market. It takes one unit of intermediate of intermediary output to make a unit of retail output, i.e. $y_{f,t} = y_{i,t}$. Following Calvo (1983), in each period a fraction $1 - \psi$ of firms can optimally reset their prices, where ψ is exogenously given. A firm that can optimally reset its price maximizes the expected sum of discounted profits. Since households directly own firms, the discount factor for nominal payouts is given by the stochastic consumer discount factor $\beta^s \Lambda_{t,t+s} (P_t/P_{t+s})$, for $s \geq 0$. Firm f 's optimization problem is

$$\begin{aligned} \max_{P_{f,t}} E_t \sum_{s=0}^{\infty} (\beta\psi)^s \Lambda_{t,t+s} (P_t/P_{t+s}) [P_{f,t} - P_{t+s}^m] y_{f,t+s} \\ s.t. y_{f,t} = (P_{f,t}/P_t)^{-\epsilon} y_t. \end{aligned}$$

By symmetry, all optimizing firms will set the same price P_t^* . Defining the relative prices $m_t = P_t^m/P_t$, $\pi_t^* = P_t^*/P_t$, and the gross inflation rate $\pi_t = P_t/P_{t-1}$ the first-order condition, written in recursive form, is given by the following expressions

$$\pi_t^* = \frac{\epsilon}{\epsilon - 1} \frac{\Xi_{1,t}}{\Xi_{2,t}}$$

$$\Xi_{1,t} = \lambda_t m_t y_t + \beta\psi E_t \pi_{t+1}^\epsilon \Xi_{1,t+1}$$

$$\Xi_{2,t} = \lambda_t y_t + \beta\psi E_t \pi_{t+1}^{\epsilon-1} \Xi_{2,t+1}.$$

Finally, by Calvo pricing, the aggregate price level evolves as

$$1 = (1 - \psi) (\pi_t^*)^{1-\epsilon} + \psi \pi_t^{\epsilon-1}.$$

Intermediate goods producers

Intermediate goods firms produce differentiated goods that are sold in a perfectly competitive market. each firm i has access to the following production technology:

$$y_{i,t} = a_t (\zeta_t k_{i,t-1})^\alpha h_{i,t}^{1-\alpha}$$

$$\log x_t = \rho_x \log x_{t-1} + \varepsilon_{x,t},$$

for $x = a, \zeta$, with $\rho_x \in [0, 1)$ and $\varepsilon_{x,t} \sim N(0, \sigma_x^2)$, where a_t denotes total factor productivity and ζ_t denotes the quality of capital. Following closely Gertler and Karadi (2011), van der Kwaak and van Wijnbergen (2014) and Kirchner and van Wijnbergen (2016), the shock ζ_t is meant to capture economic depreciation or obsolescence of capital and provides a simple source of variation in the quality of capital and thus the value of intermediary assets in the general equilibrium – it allows to simulate a financial crisis (negative shock to the capital quality) as a simple way to replicate the financial shock occurred during the 2007-2008 global financial crisis.

Each period, firm i rents labor services $h_{i,t}$ at the wage rate w_t from households. At the end of period t , the firm acquires capital $k_{i,t}$ for use in production in period $t + 1$. To finance the capital acquisition, the firm issues claims $s_{i,t}^k$ to intermediaries equal to the units of capital acquired, which pay a state-contingent net real return r_{t+1}^k at the beginning of period $t + 1$. The price of each claim is the relative price of a unit of capital q_t . After production in period $t + 1$, the firm sells the effective capital that has depreciated during that period $(1 - \delta)\zeta_{t+1}k_{i,t}$, at the price q_{t+1} . Thus, taking the relative output price m_t and the input prices q_t , r_t^k , and w_t as given, intermediate goods firms maximize the profit function

$$\max_{h_{i,t}, k_{i,t}} E_t \sum_{s=0}^{\infty} \beta^s \Lambda_{t,t+s} \Pi_{i,t+s},$$

where $\Pi_{i,t} = m_t a_t (\zeta_t k_{i,t-1})^\alpha h_{i,t}^{1-\alpha} + q_t (1 - \delta) \zeta_t k_{i,t-1} - (1 + r_t^k) q_{t-1} k_{i,t-1} - w_t h_{i,t}$ and the first-order conditions are as follows:

$$w_t = (1 - \alpha) m_t y_{i,t} / h_{i,t}$$

$$E_t \beta \Lambda_{t,t+1} q_t (1 + r_{t+1}^k) = E_t \beta \Lambda_{t,t+1} [\alpha m_{t+1} y_{i,t+1} / k_{i,t} + q_{t+1} (1 - \delta) \zeta_{t+1}] .$$

Substituting w_t in the zero profit condition that perfect competition implies, yields the ex-post return on capital to the financial intermediaries

$$r_t^k = q_{t-1}^{-1} [\alpha m_t y_{i,t} / k_{i,t-1} + q_t (1 - \delta) \zeta_t] - 1 .$$

Firms factor demands and the technology constraint yields the following expression for the relative intermediate output price

$$m_t = \alpha^{-\alpha} (1 - \alpha)^{\alpha-1} a_t^{-1} \left\{ w_t^{1-\alpha} [q_{t-1} (1 + r_t^k) \zeta_t^{-1} - q_t (1 - \delta)]^\alpha \right\} .$$

Capital producing firms

At the end of period t , when intermediate goods firms have produced, the capital producers buy the remaining stock of capital $(1 - \delta) \zeta_t k_{t-1}$ from the intermediate goods producers at price q_t . They combine this capital with goods bought from the final goods producers (investment i_t) to produce next period's beginning of period capital stock k_t . This capital is being sold to the intermediary goods producer at price q_t . It is assumed that the capital producers face convex adjustment costs when transforming the final goods bought into capital goods, set up such that changing the level of gross investment is costly. The capital production technology is given by

$$k_t = (1 - \delta) \zeta_t k_{t-1} + (1 - \Psi(\iota_t)) i_t \quad \Psi(\iota_t) = \frac{\gamma}{2} (\iota_t - 1)^2, \quad \iota_t = i_t / i_{t-1} .$$

Profits are passed on to the households, who own the capital producers. The profit at the end of period t equals is given by $q_t k_t - q_t (1 - \delta) \zeta_t k_{t-1} - i_t$. The problem of the capital producer is then to solve

$$\max_{i_t} E_t \sum_{s=0}^{\infty} \beta^s \Lambda_{t,t+s} \{q_{t+s} [1 - \Psi(\iota_{t+s})] - 1\} i_{t+s} ,$$

taking q_t as given. the first-order condition is as follows

$$q_t [1 - \Psi(\iota_t)] - 1 - q_t \iota_t \Psi'(\iota_t) + \beta E_t \Lambda_{t,t+1} q_{t+1} \iota_{t+1} \Psi'(\iota_{t+1}) = 0 ,$$

which gives the following expression for the price of capital

$$\begin{aligned} \frac{1}{q_t} = & 1 - \frac{\gamma}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 - \frac{\gamma i_t}{i_{t-1}} \left(\frac{i_t}{i_{t-1}} - 1 \right) \\ & + \beta E_t \left[\Lambda_{t,t+1} \frac{q_{t+1}}{q_t} \left(\frac{i_{t+1}}{i_t} \right)^2 \gamma \left(\frac{i_{t+1}}{i_t} - 1 \right) \right] . \end{aligned}$$

2.2.4 Fiscal policy

The government engages in public spending in every period. Public spending (g_t) consists of a highly persistent component g_t^P and a transitory component g_t^T :

$$\log \left(\frac{g_t}{\bar{g}} \right) = \log \left(\frac{g_t^P}{\bar{g}} \right) + \log (g_t^T). \quad (2.9)$$

The persistent component represents the rigidity in public expenditures. Social benefits, intermediate government consumption and compensation of public employees are usually identified as spending categories that are more rigid and generally difficult to reverse and, therefore, translate into longer-lasting budgetary effects. The transitory component symbolizes discretionary fiscal policy that is meant to be short-lived (*e.g.*, spending one-offs, period subsidy, or any legislated temporary spending policy). Specifically, components in (2.9) follow a first-order autoregressive process:

$$\log \left(\frac{g_t^P}{\bar{g}} \right) = \rho_P \log \left(\frac{g_{t-1}^P}{\bar{g}} \right) + \varepsilon_{P,t}, \quad \varepsilon_{P,t} \sim N(0, \sigma_P^2) \quad (2.10)$$

$$\log (g_t^T) = \rho_T \log (g_{t-1}^T) + \varepsilon_{T,t}, \quad \varepsilon_{T,t} \sim N(0, \sigma_T^2), \quad (2.11)$$

with $\rho_P \in (0, 1)$, $\rho_T \in [0, 1)$, $\rho_P > \rho_T$ and $\bar{g} > 0$, the steady-state level of government consumption. A conventional assumption in the DSGE literature is that rational agents have perfect information about fiscal policy. Although there are many circumstances in which the composition and trajectory of fiscal policy are less clear. The difficulty of distinguishing permanent from temporary changes in fiscal policy is a major source of fiscal policy uncertainty (*e.g.*, Baker et al., 2016; Hollmayr and Matthes, 2015). Moreover, the literature concludes that uncertainty about permanent changes in policy has important effects on economic activity (*e.g.*, Bi et al., 2013). This paper relaxes the assumption that agents perfectly observe the entire state and instead considers a model of passive learning.³ Agents behave fully rational given their information sets. Agents observe aggregate public consumption g_t but neither the exact realization of its persistent nor its transitory component. In addition, agents observe a noisy signal about the persistent component

³See Evans et al. (2009), Mitra et al. (2013), Caprioli (2015) and Fève and Pietrunti (2016) for some examples of the application of imperfect information and learning framework to fiscal policy issues.

$$\log(z_t) = \log\left(\frac{g_t^P}{\bar{g}}\right) + \varepsilon_{z,t}, \quad \varepsilon_{z,t} \sim N(0, \sigma_z^2), \quad (2.12)$$

where σ_z measures the precision of the signal. A shock to the signal is defined as a noise shock. The signal conveys information that helps agents to infer the actual level of rigid public expenditure and the expected fiscal consequences. The additional information comprises, for example, fiscal stance reports of Independent Fiscal Institutions and rating agencies, fiscal forecast analysis, or sector statistics of the economy.

The economic agents form expectations of the future government spending based on their observations of current government spending (g_t), their knowledge of the driving process of fiscal policy shocks (ρ_P , ρ_T , σ_P^2 , σ_T^2 and $\bar{g}$) and observing the noisy signal z_t . Given that information, the Kalman filter is used to derive agents' expectations of the future government spending. In order to use the Kalman filter, definition (2.9), policy rules (2.10) and (2.11) and the process (2.12) are converted into the following state-space representation (see the appendix for a detailed derivation):

$$\begin{aligned} x_t &= H \cdot \xi_t + S\varepsilon_t, \\ \xi_t &= F \cdot \xi_{t-1} + R\varepsilon_t, \end{aligned}$$

where $x_t = \left[\log\left(\frac{g_t}{\bar{g}}\right), \log(z_t) \right]'$ is the observed variables vector, the vector of unobserved variables is given by $\xi_t = \left[\log\left(\frac{g_t^P}{\bar{g}}\right), \log(g_t^T) \right]'$, H and F are matrices of parameters, and $\varepsilon_t = [\varepsilon_{P,t}, \varepsilon_{T,t}, \varepsilon_{z,t}]'$ is a vector that contains all structural shocks.

The government finances its expenditures by levying lump-sum taxes on households and by issuing long-term bonds to bankers. Taxes follow the rule

$$\tau_t = \bar{\tau} + \kappa (s_t^b - s^b), \quad (2.13)$$

with $\kappa > 0$ and $\bar{\tau} > 0$, in order to ensure fiscal solvency at any finite initial level of debt. The law of motion for the stock of debt, which equals the stock of government debt held by banks, is given by the government resource constraint

$$s_t^b = g_t - \tau_t + (1 + r_t^b) s_{t-1}^b. \quad (2.14)$$

2.2.5 Aggregate resource constraint and monetary policy

Output is divided between consumption, investment and government consumption. The economy-wide resource constraint is thus given by

$$y_t = c_t + i_t + g_t.$$

Equilibrium requires that the number of claims owned by the financial intermediaries must be equal to aggregate capital, $s_t^k = k_t$, while the number of government bonds owned by the financial sector must be equal to the number of bonds issued by the government, $s_t^b = b_t$.

The monetary authority is assumed to set the risk-free nominal interest rate on deposits, r_t^n , to stabilize inflation and output according to a Taylor rule of the form

$$r_t^n = (1 - \rho_r) [r^n + \gamma_\pi (\pi_t - \bar{\pi}) + \gamma_y \log (y_t/y_{t-1})] + \rho_r r_{t-1}^n, \quad (2.15)$$

with $\gamma_\pi > 1$, $\gamma_y \geq 0$, $\rho_r \in [0, 1)$ and $\bar{\pi} \geq 1$, which stands for the inflation target. The link between nominal and real interest rates is given by the following Fisher relation

$$1 + r_t^d = (1 + r_{t-1}^n) \pi_t^{-1}. \quad (2.16)$$

2.2.6 Fiscal limit and sovereign default

In this paper it is assumed that the default scheme at each period depends on an effective fiscal limit (b_t^{lim}). If current debt obligations are below the effective fiscal limit, then the government pays its liabilities, otherwise the government defaults. As in Ghosh et al. (2013), the fiscal limit is a debt-limit. The default indicator (Δ_t) is summarized by:

$$\Delta_t = \begin{cases} 0 & \text{if } b_t < b_t^{\text{lim}} \\ 1 & \text{if } b_t \geq b_t^{\text{lim}} \end{cases}.$$

Bi (2012) argues that the size of government purchases and lump-sum transfers in conjunction with dynamic Laffer curves play a crucial role in generating sovereign risk premium. Furthermore, it is common to assume in the literature (*e.g.*, Arellano, 2008; Leeper and Walker, 2011; Bi et al., 2014) that the probability of sovereign default depends on the level of public debt or debt-to-GDP ratio. Following Bi (2012), the operationalisation of sovereign default is done by assuming that the

Table 2.2: Regression for debt-limit function regression

	constant	$\frac{g_t^P}{\tau_t}$	$\frac{b_t}{y_t}$
Debt-limit: b_t^{lim}	1.61	-0.36	-0.02
Adj. R-squared: 0.1990	(0.0991)*	(0.1468)*	(0.0273)
	(full sample)		
Debt-limit: b_t^{lim}	1.61	-0.40	
Adj. R-squared: 0.2334	(0.0994)*	(0.1243)*	
	(full sample)		
Debt-limit: b_t^{lim}	1.57	-0.42	
Adj. R-squared: 0.3246	(0.1192)*	(0.1378)*	
	(sample excluding ea12)		

Data sources: AMECO - European Commission, data for the year 2007, fiscal limit from Ghosh et al. (2013).

Notes: robust standard errors in brackets, * indicates a p-value ≤ 0.05

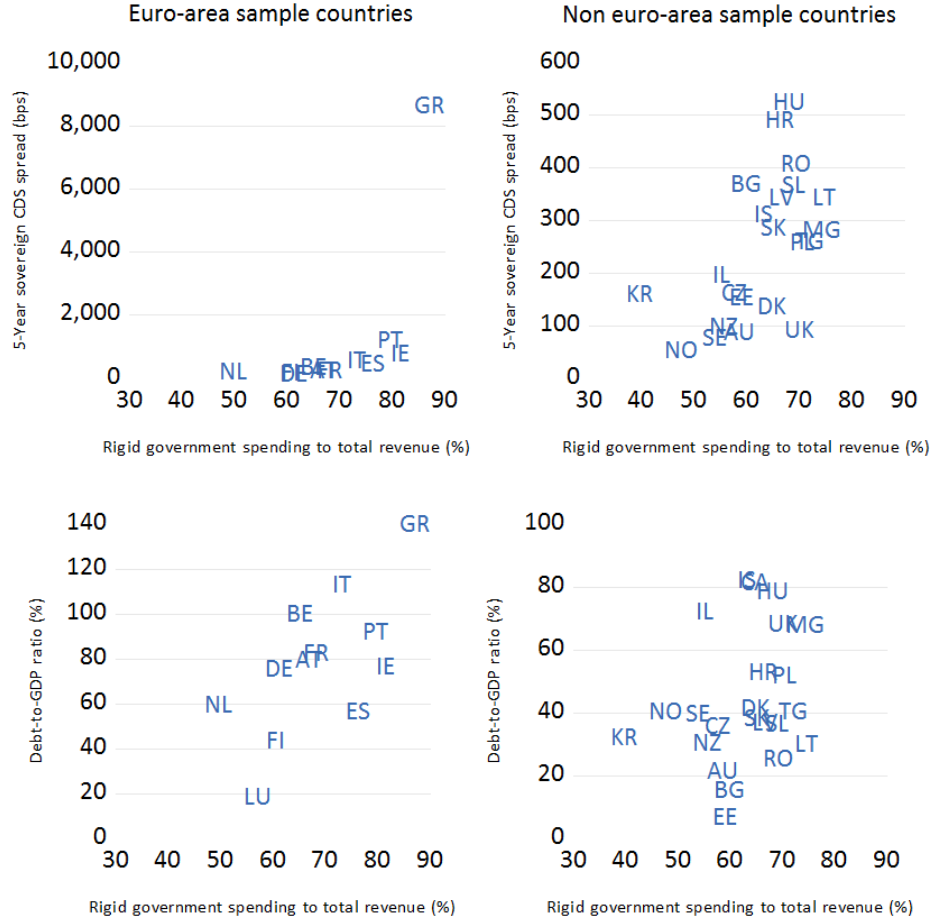
fiscal limit is a function of: (i) the ratio of persistent government spending to total revenue; and (ii) of the debt-to-GDP ratio:

$$b_t^{\text{lim}} = \varrho_0 \left(\frac{g_t^P}{\tau_t} \right)^{\varrho_1} \left(\frac{b_t}{y_t} \right)^{\varrho_2}.$$

The ratio of persistent government spending to total revenue provides a proxy for fiscal effort. The higher the ratio of persistent spending on revenue, the less space a government has to accommodate cyclical fluctuations in the revenue, and depending on the initial debt level, it is expected to drop fiscal limit. To illustrate this point, Table 2.2 presents estimations for the debt-limit function. It summarizes a non-linear least squares regression of the debt-limit as taken from Ghosh et al. (2013), on the ratio of persistent government spending (as measured by the sum of social benefits, public employees compensations and interest spending) to total revenue and on the debt-to-GDP ratio. A negative and statistically significant relation is found between the debt-limit and the ratio of persistent public spending on total revenues.⁴

⁴See Figure 2.12, in Appendix, for the residuals of the regression that uses the full sample of countries and drops debt-to-GDP ratio as independent variable.

Figure 2.2: Sovereign risk, debt and rigid public spending (2011)



The inclusion of debt-to-GDP ratio revealed irrelevant as the persistent spending to revenues ratio figures as a better fiscal stress indicator and is highly correlated with the former. This correlation is depicted in Figure 2.2, from where one can observe the linear relation between debt -to-GDP ratio and persist spending to revenues ratio, both for euro-area and non euro-area countries. Naturally, the link between this fiscal stress variable and sovereign risk emerges, having the same non-linear relation with sovereign risk as the debt level (Figure 2.1). For the sample countries, risk premium rise disproportionately as the ratio of persistent spending to total revenue rises approximately above 75%.

Following Corsetti et al. (2013), the *ex ante* probability of default (p_t^{df}), for a certain g_t^P/τ_t ratio, will be given by the cumulative distribution function of the following beta distribution:

$$p_t^{df} = F_{beta} \left(\frac{g_t^P}{\tau_t}; \alpha_{df}; \beta_{df} \right) .$$

The incorporation of sovereign default implies that the returns to the financial intermediaries holding the sovereign debt are of course affected. A default inclusive return is given by

$$1 + r_t^{b*} = (1 - \Delta_t) (1 + r_t^b) .$$

Replacing r_t^b by r_t^{b*} in the model is sufficient to capture the direct impact of the possible default on financial intermediaries.

Although it is known that sovereign risk premia is affected by distinct fiscal variables,⁵ this framework allows to keep the exercise tractable while focus on the effects of information frictions on sovereign risk. De Grauwe and Ji (2012), for instance, show that a substantial portion of the movements in sovereign risk premia during the recent sovereign debt crisis were unrelated to country fundamentals. By introducing imperfect information in this paper, the sovereign risk reacts to non-fundamental factors particularly through a noise shock in persistent government spending.

2.3 Model analysis

This section presents the main results regarding the interaction between imperfect information on the composition of public spending and sovereign risk. First the main features of the model are shown through the simulated effects of a public spending shock in the calibrated economy. Some sensibility analysis of the results on the fiscal multiplier is performed with respect to the degree of imperfect information and to the persistence of the public spending shock. In order to illustrate the pure expectations mechanism embedded in the model due to the presence of imperfect fiscal information, a particular point is highlighted on the effects of a persistent government spending noise shock. Finally, the analysis focus on the simulated response of fiscal policy to a financial crisis under imperfect information. The idea is to bring the pre-sovereign debt crisis in euro area framework (described in introduction) into this model and to assess the effects of different public spending stimulus under imperfect information. In all exercises made in this paper, impulse responses with sovereign risk are shown but without actual default.

⁵See, among others, Reinhart and Sack (2000); Ardagna et al. (2007); Bernoth et al. (2012).

2.3.1 Calibration

This paper follows closely Gertler and Karadi (2011), van der Kwaak and van Wijnbergen (2014) and Kirchner and van Wijnbergen (2016) in financial frictions modeling. The parameters are chosen identically to the calibration used in these papers, which allow for comparability with the existing literature using similar DSGE models (with financial frictions but under perfect information assumption). Therefore, regarding the conventional parameters, for the discount factor β , the degree of habit formation h , the inverse Frisch elasticity of labor supply φ , the capital share α , the Calvo probability of keeping prices fixed ψ , the elasticity of substitution between goods ϵ , the depreciation rate δ and the investment adjustment cost parameter γ , standard values are chosen. With respect to monetary policy, the coefficient on inflation in the Taylor rule is set to a customary value of $\gamma_\pi = 1.5$, the coefficient on output is $\gamma_y = 0.125$, and the interest rate smoothing parameter is set to $\rho_r = 0.8$. For the parameters related to the financial sector, the steady state leverage ratio is set to $\phi = 4$, the steady state credit spread Γ is set to match pre-2007 spreads of bank lending rates to risk-free bonds, the average survival probability of bankers is set to $\theta = 0.938$, that implies an expected horizon of approximately 4 years for bankers.

Regarding the fiscal policy coefficients, the total government expenditure share $\bar{g}/\bar{y}$ is set to 20 and the steady state debt-to-GDP ratio $\bar{b}/\bar{y}$ is set to 2.4, which implies a 60% ratio in annual terms. Both components of government expenditure have implicit an AR(1) process, with the persistent component assuming a coefficient $\rho_P = 0.9$ and the temporary component $\rho_T = 0.4$. This calibration implies a debt-limit in steady state of 5.3 or 133% of GDP in annual terms. The parameters of beta distribution are set in order to reflect the data - i.e., that risk premium appears to rise disproportionately as the ratio of persistent spending to total revenue rises (see Figure 2.2). Accordingly, these parameters are calibrated as $\alpha_{df} = 2.3$; $\beta_{df} = 0.75$. Table 2.3 lists the calibrated parameters in the model.

Table 2.3: Model parameters and steady state values

Parameter	Value	Definition
<i>Households</i>		
β	0.990	Discount rate
h	0.815	Habit parameter
φ	0.276	Inverse Frisch elasticity of labor supply
<i>Financial intermediaries</i>		
λ^*	0.220	Fraction of assets that can be diverted
θ	0.938	Survival probability of bankers
χ	0.044	Proportional transfer to entering bankers
<i>Goods-producing firms</i>		
α	0.330	Capital share
ψ	0.779	Calvo pricing parameter
ϵ	4.167	Elasticity of substitution between goods
<i>Capital-producing firms</i>		
δ	0.025	Depreciation rate
γ	1.728	Investment adjustment cost parameter
<i>Monetary policy</i>		
γ_π	1.500	Inflation coefficient in the Taylor rule
γ_y	0.125	Output coefficient in the Taylor rule
ρ_r	0.800	Interest rate smoothing parameter
<i>Fiscal policy</i>		
ρ_P	0.900	Persistence of rigid gov. spending component
ρ_T	0.400	Persistence of temporary gov. spending component
κ	0.010	Government debt feedback on taxes
<i>Steady state values</i>		
$\bar{g}/\bar{y}$	0.200	Government spending to GDP ratio
$\bar{b}/\bar{y}$	2.400	Government debt to GDP ratio
ϕ	4.000	Banks' leverage ratio
Γ	0.003	Banks' credit spread
r^d	0.010	Households' return on deposits
r^b	0.010	Banks' return on government bonds
r^k	0.013	Banks' return on capital
r^e	0.020	Banks' return on equity

2.3.2 Surprise public spending shock

Figures 2.3 and 2.4 show the dynamics of the response of selected variables to surprise shocks on persistent and transitory components of public spending, which are normalized to 1% of GDP on impact. When agents have perfect information about the economy (blue Impulse Response Functions), the fiscal expansion with intermediary financing of public debt raises both expected interest rates and credit spreads through the associated tightening of bank balance sheet constraints and intermediary balance sheet adjustments. When the shock hits the economy, the debt-limit ratio drops, paralleled with a rise in probability of default, reflecting an increase in fiscal stress due to the rise of persistent public spending and the drop in revenues (Figure 2.5, black IRFs). As a consequence of the rise in borrowing costs, the demand for capital and thus investment is crowded out. The fall in investment is amplified by the financial accelerator mechanism as in Gertler and Karadi (2011) and the procyclical variation in intermediary balance sheets amplifies further the negative effect. Falling investment leads to a falling price of capital, which further raises borrowing costs with the already mentioned consequences. These effects feed through the whole economy as falling wages discourage household labor supply and as the associated tightening of the households' budget constraints depresses consumption.

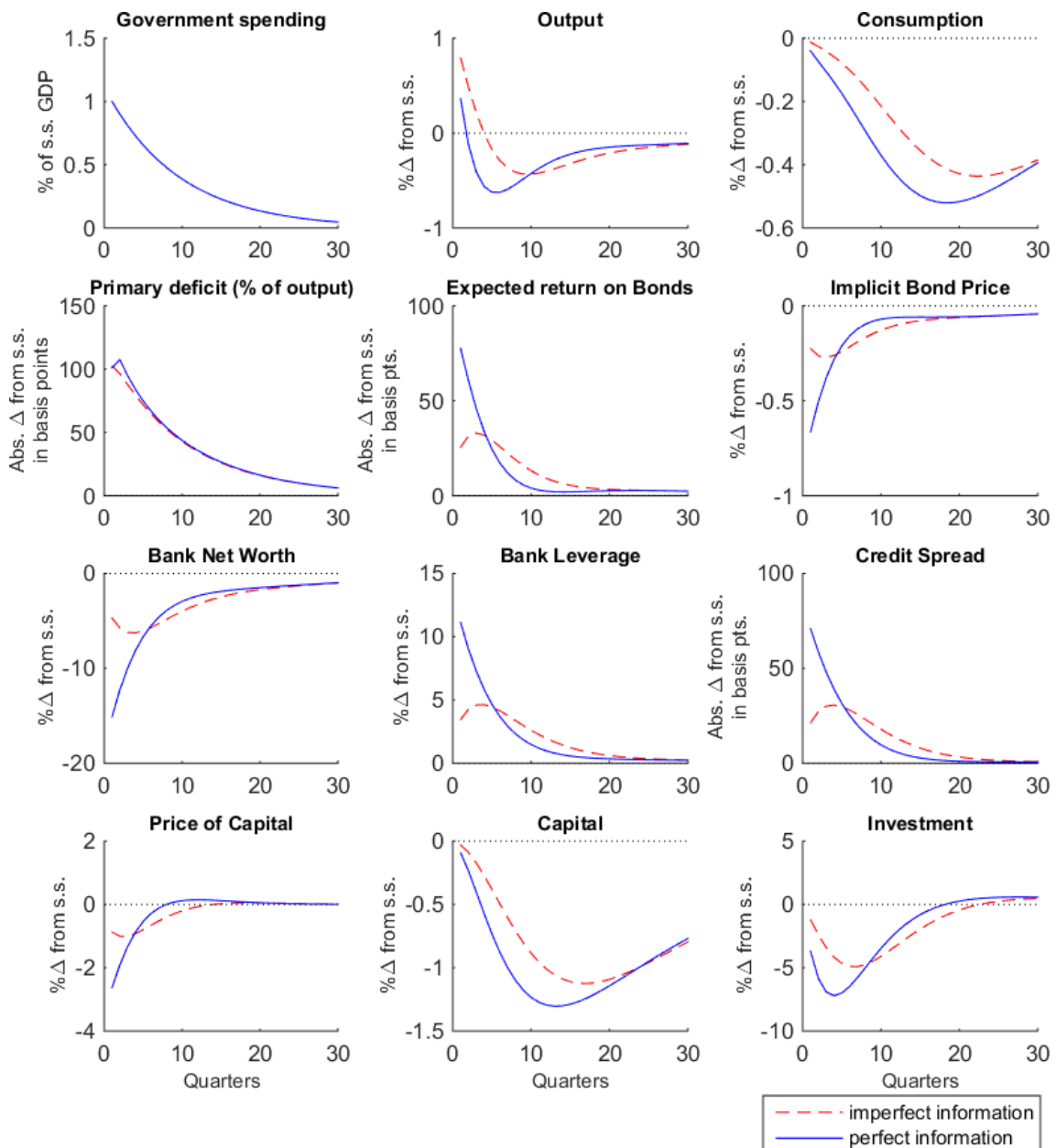
When agents have imperfect information regarding the composition of the public spending shock (red and green IRFs) they have to learn about its true nature – transitory or persistent. As explained in the previous section, agents only observe aggregate public spending and a noisy signal about the persistent component.

Regarding the persistent spending shock, when the shock hits the economy the agents initially believe that there is a probability that spending shock is transitory, so the fiscal expansion generates the expectation of smaller fiscal deficits in the future and, subsequently, the fall in the demand for bonds is smaller than with perfect information, as well as the drop in debt-limit which holds back the rise in the sovereign default probability. This explains the smaller reduction in implicit bond prices and raising in *ex-ante* nominal interest rate bonds. The increasing in expected real rate on bonds is lessened, mitigating the rise in the expected overall bank portfolio return and the incentive to accumulate assets. This incentive restricts banks' assets demand through the smaller tightening of leverage constraints, raising the costs of credit to both the government and intermediary goods firms below the perfect information scenario. The consequence of the smaller rise in borrowing costs is the smaller crowding out of investment and demand for capital. With lessened falling wages household labor supply does not drop as much as with perfect

information, so the households' budget constraint is less tightened and the negative effect on consumption is reduced.

The combination of the reduced negative effect on private consumption and the smaller crowding out of investment leads to an impact multiplier of a persistent government spending shock on output higher than with perfect information.

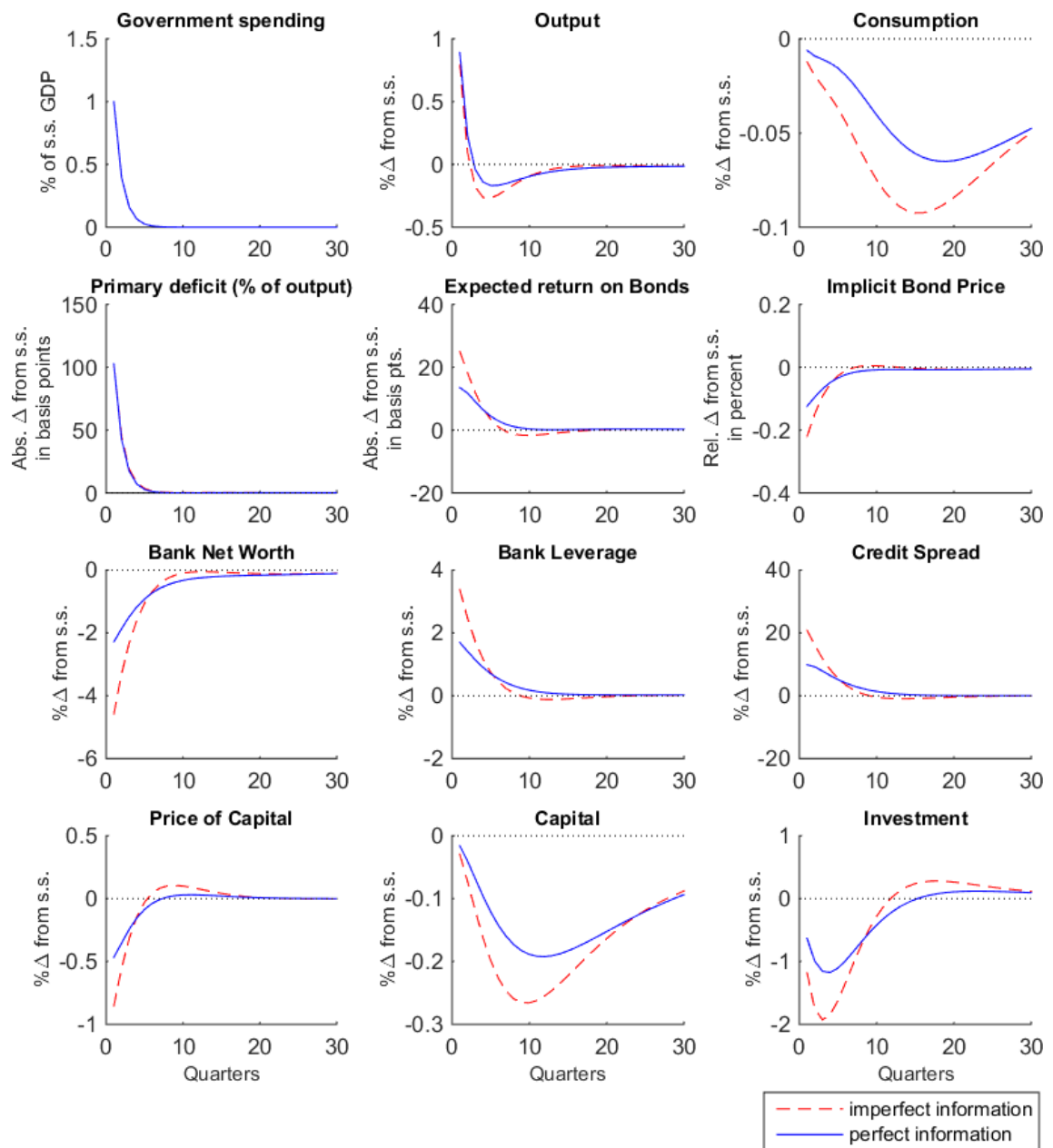
Figure 2.3: IRFs to a 1% GDP shock in persistent public spending



An opposite dynamic within the same mechanism occurs when a transitory public spending shock hits the economy under imperfect information (Figure 2.4). Agents initially misread the shock and attribute a probability that it is persistent, so the

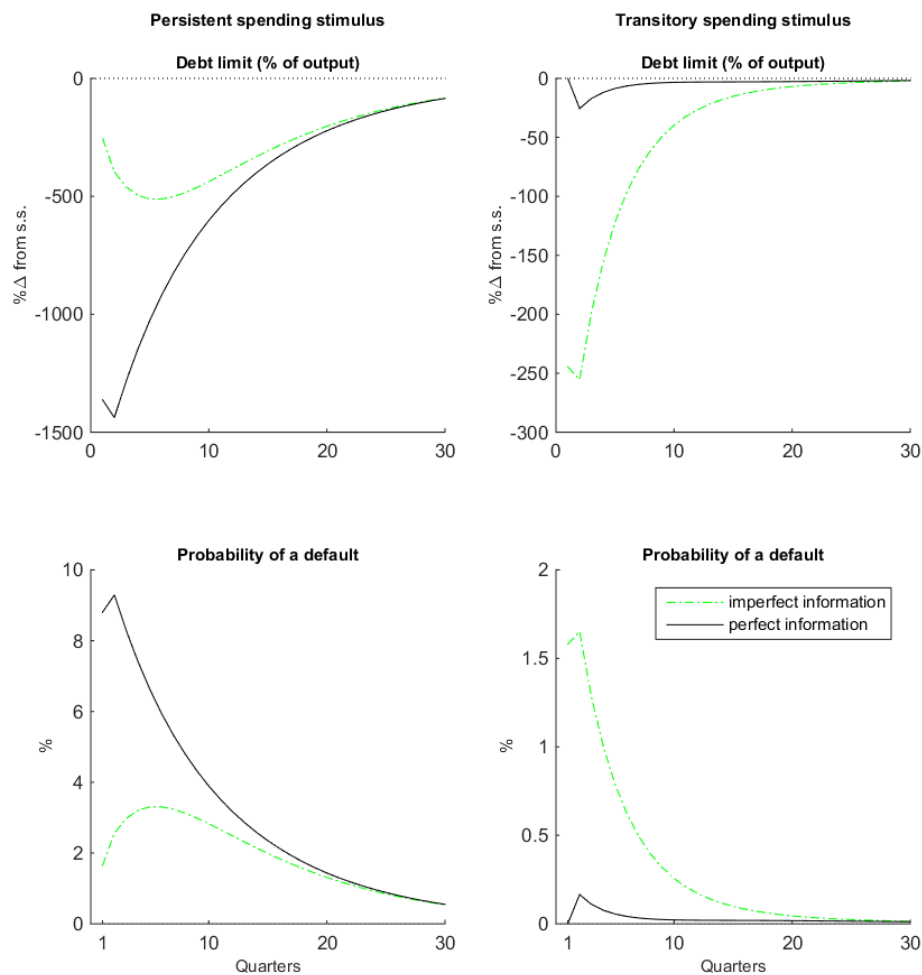
fiscal expansion generates the expectation of higher fiscal deficits in the future and, subsequently, the debt-limit drops, the probability of sovereign default rises substantially, and the fall in the demand for bonds is higher than with perfect information. Higher expected interest rates and credit spreads intensify the crowding out of investment and the demand for capital. A more restrictive budget constraint leads households to consume less than under perfect information which, in turn, alongside with a deeper crowding out of investment, generates a smaller output multiplier on impact.

Figure 2.4: IRFs to a 1% GDP shock in transitory public spending



The results suggest that, through the expectations channel, imperfect information improves the efficiency of a persistent public spending shock, as for the same level of persistence information frictions lead to higher output effects after a persistent public spending shock. The reason is that, as agents learn about the true nature of the shock, they do not fully incorporate the costs of the persistent policy in their optimization problem, amplifying the business cycle effects. The same mechanism rises the costs of transitory spending shocks under imperfect information. Nonetheless, for any specific level of information, less persistent spending policies are more efficient.

Figure 2.5: Debt-limit and probability of default after a 1% GDP shock in public spending



2.3.3 Fiscal multiplier, spending rigidity and imperfect information

To assess how the degree of imperfect information and the persistence of public spending affect the results, Figure 2.6 and Figure 2.7 display a sensibility analysis of the impact spending multiplier. Sensibility analysis with respect to imperfect information is performed resorting to variations in the signal-to-noise ratio, $\nu = \sigma_P/\sigma_z$. Starting with a calibration of $\nu = 0.05$, a smaller (greater) ratio implies greater (smaller) degree of imperfect information.

Figure 2.6: Impact multiplier for different persistence and imperfect information degrees of rigid public spending

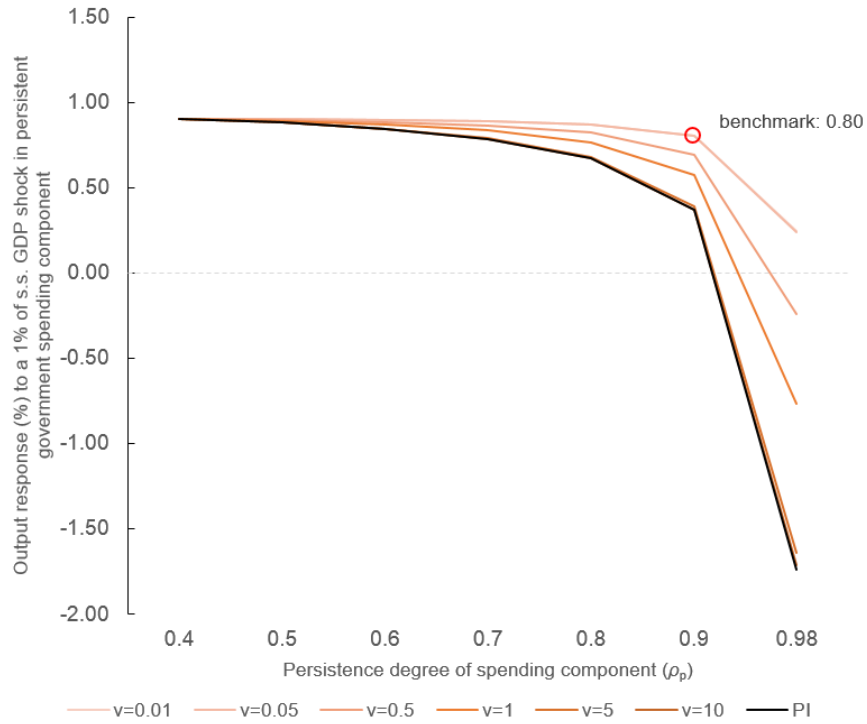
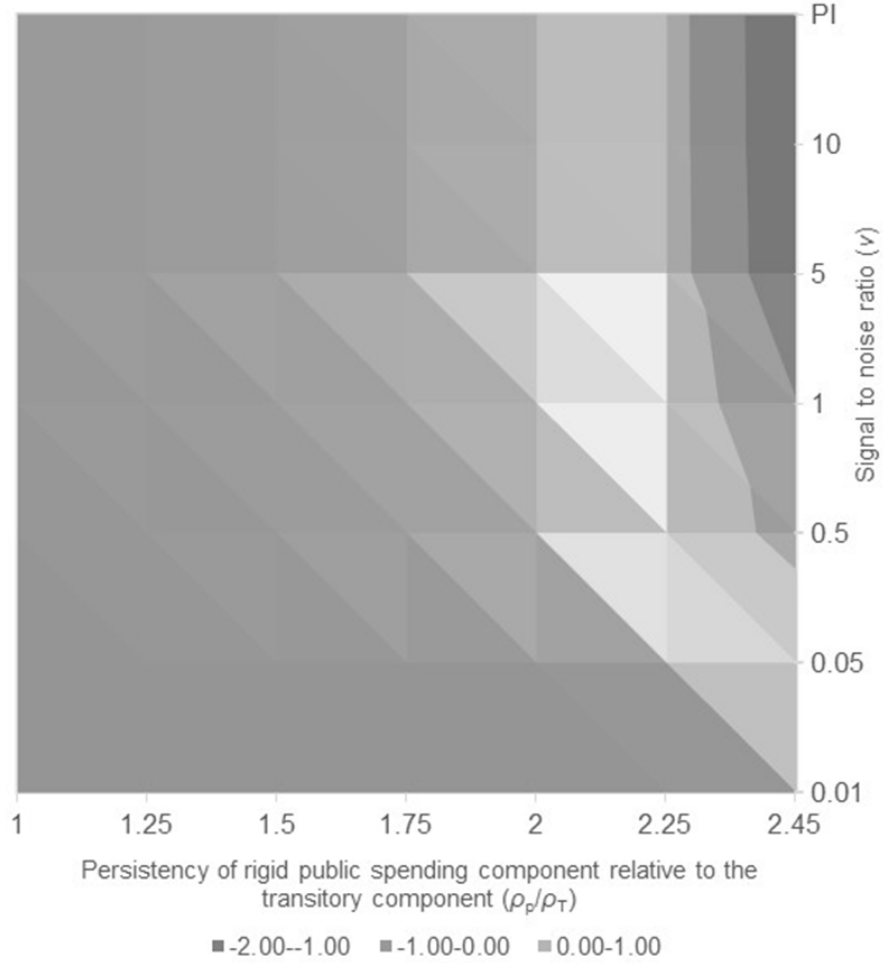


Figure 2.6 reveals that for a persistent public spending shock, less information and less persistent policies increase the impact multiplier on output. When the persistence of the rigid spending component equals that of the transitory component ($\rho_P = \rho_T = 0.4$) it mutes the agent's learning dynamics and the results equals that under perfect information. For a given level of information ν , less persistence translates into higher output effects on impact due to the less existing financing costs as discussed above. For a given ρ_P , less information origins higher output effects through the expectations channel: agents are not able to fully anticipate the future costs of the policy.

Figure 2.7: Relative impact multiplier public spending



Analyzing the impact multiplier of persistent spending relative to the impact multiplier of transitory spending, Figure 2.7 reinforces the previous conclusion, as for a given information level, the adoption of high persistent policies compared with transitory ones ($\frac{\rho_P}{\rho_T} > 1$) lead to significant reductions, or even losses (darker region in Figure 2.7) in the output multiplier. The only exception is for the framework where imperfect information about spending composition is very high ($\nu = 0.01$), as the impact multiplier is similar among persistent and transitory spending shocks.

2.3.4 Fiscal noise shock

The study of a fiscal noise shock reveals the pure fiscal expectation mechanism behind this model since there is no true fiscal shock, only an information shock regarding the signal on the persistent public spending component. The practical interest of this example is that agents react to fiscal signals that are non-fundamental,

for example, the signal can be the discussion of a public spending policy project that never gets legislated, or the noise generated by the press trying to put under scrutiny the government fiscal reaction to a crisis.

Figure 2.8: IRFs to 1SE shock in public spending noise

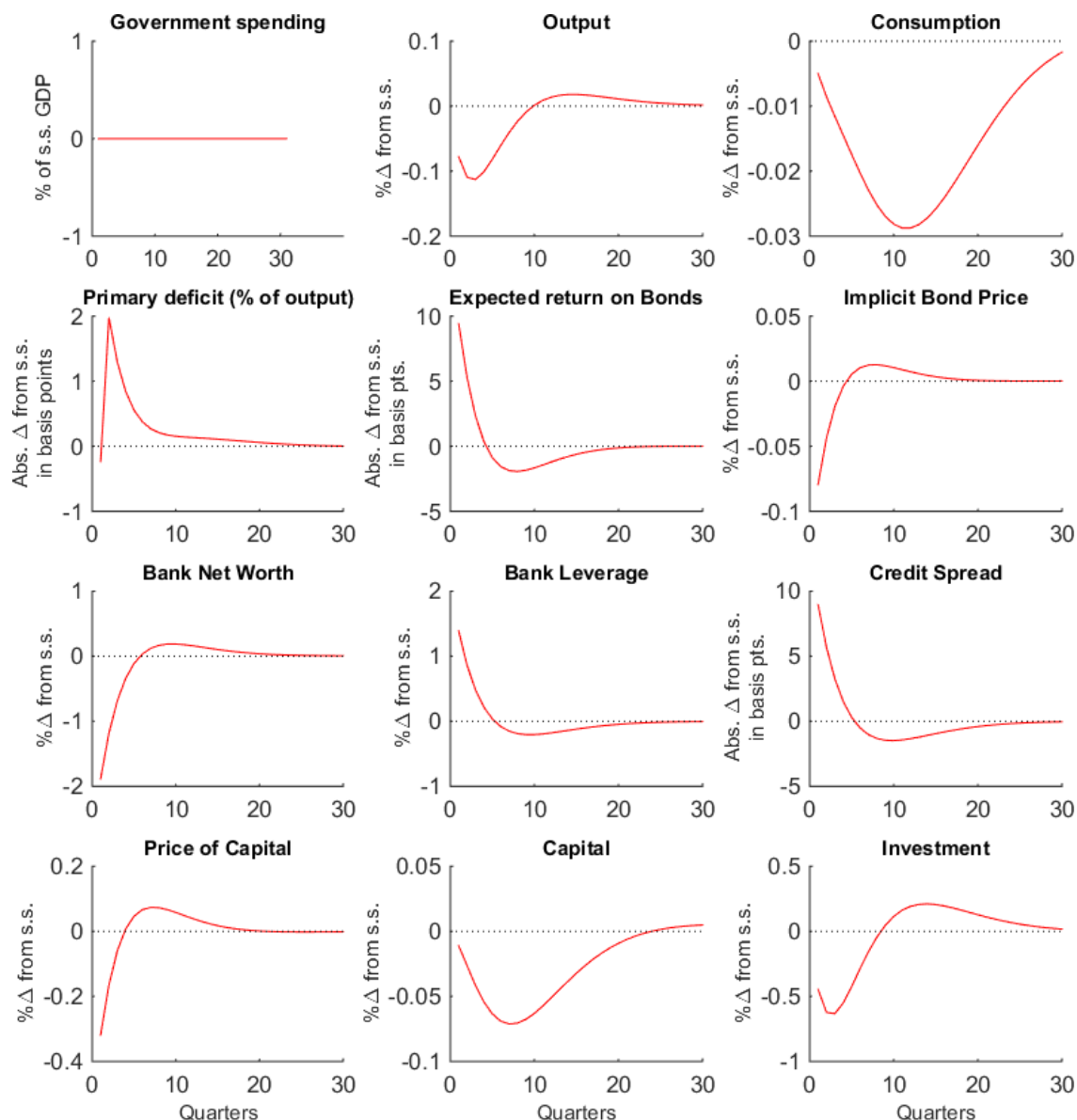
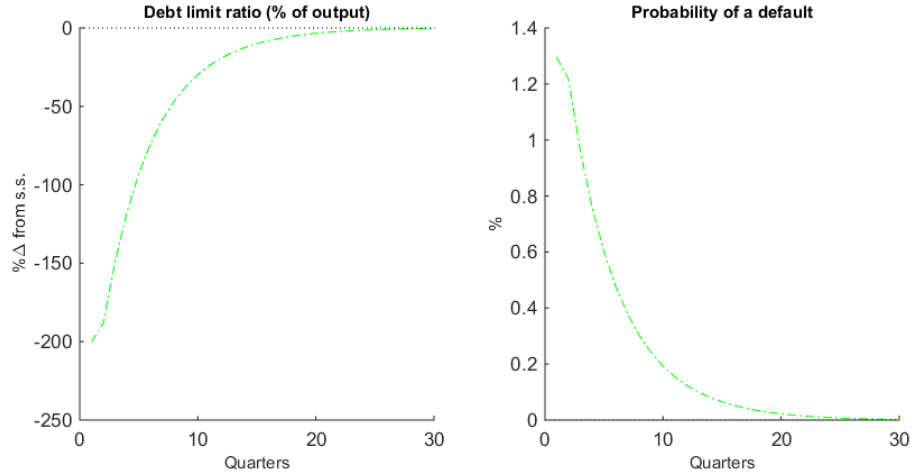


Figure 2.8 shows the response of the economy to a 1SE positive shock in the noisy signal about the persistent component of public spending – due to the signal extraction framework, a positive noise shock implies that agents have to lean if there is a positive persistent spending shock or if it is just noise. The results show that, although there is no actual increase in government spending, agents attribute a probability that there will be future debt financed persistent deficits.

A higher expected persistent spending on revenues ratio, fuels a rise in the probability of sovereign default and a drop in the debt-limit ratio (Figure 2.9). The deficit financing subject to agency frictions leads to the tightening of bank balance sheet constraints and, subsequently, to the rise of expected interest rates and credit spreads. Investment drops as borrowing costs rise, leading to a fall in the price of capital which lowers banks net worth and thus further tightens intermediary constraints, feeding an amplification financial mechanism which further raises borrowing costs. The output drops temporarily due to the fall in investment and consumption. In a framework with financial frictions, non-fundamental fiscal shocks have business cycle effects due to the interaction of banks' balance sheet adjustments, leverage constraints and the expectation of future debt financed fiscal deficits.

Figure 2.9: Debt-limit and probability of default after a 1SE shock in public spending noise



As a pure noise shock has impact on debt-limit ratio, credit spreads and on the probability of sovereign default, in an economy facing severe limitations of fiscal space, an adverse noisy fiscal shock could be enough to trigger a recession and sovereign default, if the country loses access to markets to finance its debt.

2.3.5 Fiscal response to a financial crisis

This section turns the attention to the effects of the nature of fiscal response during a crisis. Following closely Gertler and Karadi (2011) and Kirchner and van Wijnbergen (2016), a financial crisis is simulated through a negative shock to the capital quality (ζ_t): capital quality drops 5% on impact with autocorrelation coefficient $\rho_\zeta = 0.5$, triggering a response similar in terms of type, magnitude and duration the the recent

crisis. The smoothing parameter ρ_r in the Taylor rule is reduced by half. In order to reflect the stabilization role of fiscal policy, this exercise considers an announced fiscal stimulus, implemented one quarter after the initial shock. Comparing with the exercise in section 2.3.2, the magnitude of the government spending shock was amplified, to mimic the sizable fiscal stimulus packages in euro area after the global financial crisis. The autoregressive coefficient of the transitory component of government spending is set such that the duration of policy is one year, and that of the persistent component now assumes $\rho_P = 0.98$ in order to exemplify an extreme scenario of persistent policy and create contrast with the transitory one. The calibration of the remaining parameters are kept as in the previous exercise, which follow the calibration adopted for advanced economies such as the US and euro area (*e.g.*, Smets and Wouters, 2007 and Gertler and Karadi, 2011). Figures 2.10 and 2.11 illustrate the effects of using, respectively, rigid (persistent) and transitory government spending to counteract the recession.

As shown in Figure 2.10, for a government that uses persistent spending as an instrument, when the shock hits the economy, the deterioration in intermediary asset quality produces a sharp recession with output declining close to 8% as intermediary net worth drops and credit tightens, leading to a sharp rise in the credit spread. Investment initially drops sharply and takes more than three years to recover; as a consequence, output takes more than five years to reach pre-shock levels again.

When the financial shock hits the economy, the government announces that one quarter after there will be a public spending stimulus of 2% of GDP. Under imperfect information (red IRFs), the nature of that stimulus is not known yet, only total spending and a noisy signal of the persistent component are observed. After the fiscal stimulus announcement (at $t = 0$), the fall in output is amplified due to credit tightening as expected fiscal deficits rise, as previously discussed. The debt-limit ratio drops and the probability of sovereign default rises due to the drop in revenue and to the rising expectations about the persistence nature of fiscal policy. Imperfect information leads agents to misread the true nature of the fiscal shock: they consider some probability that the shock is transitory, so the contemporary negative effect of expected debt financed persistent fiscal deficits is lessened.

Figure 2.10: Public spending shock to counteract a negative capital quality shock

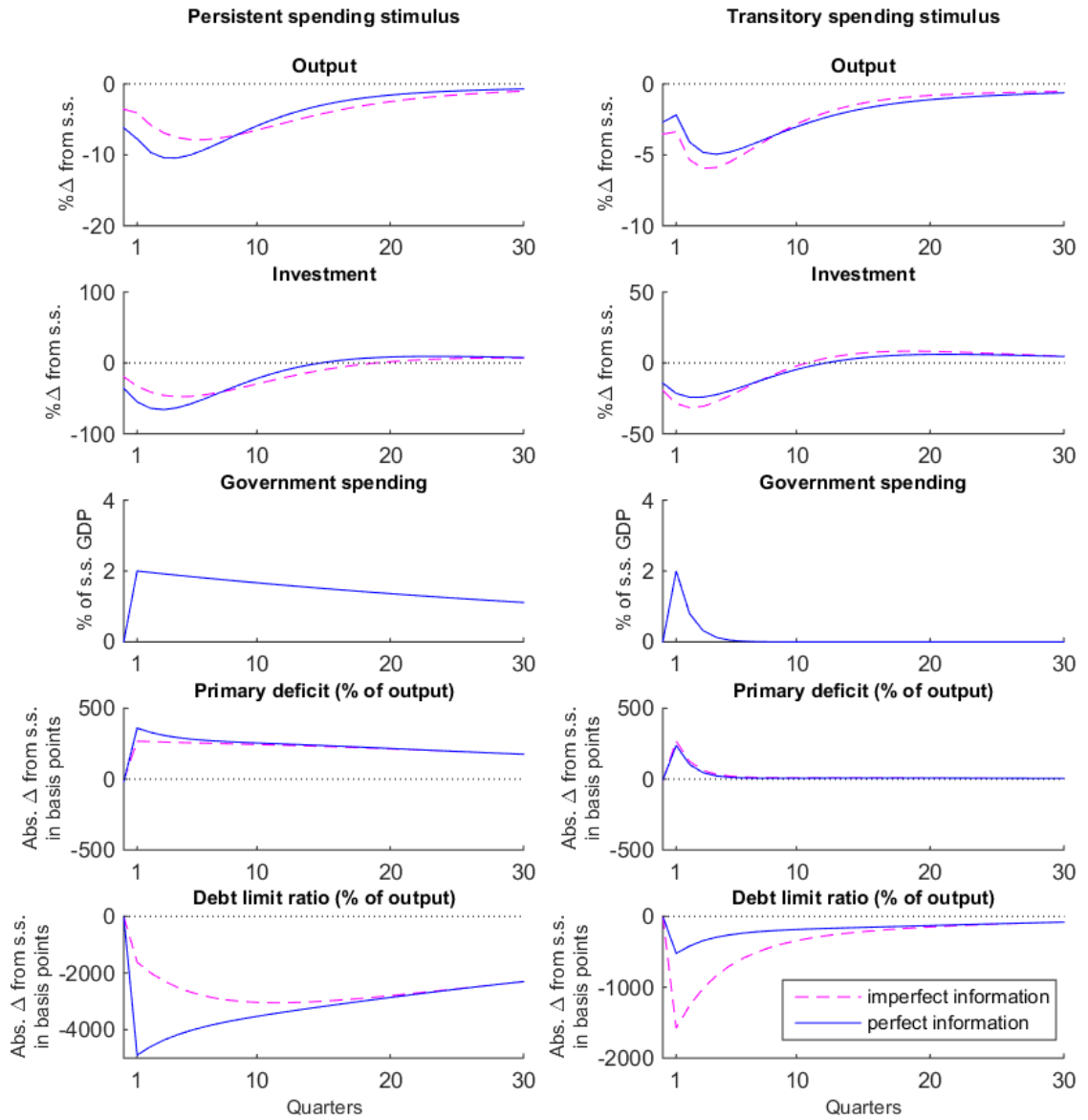
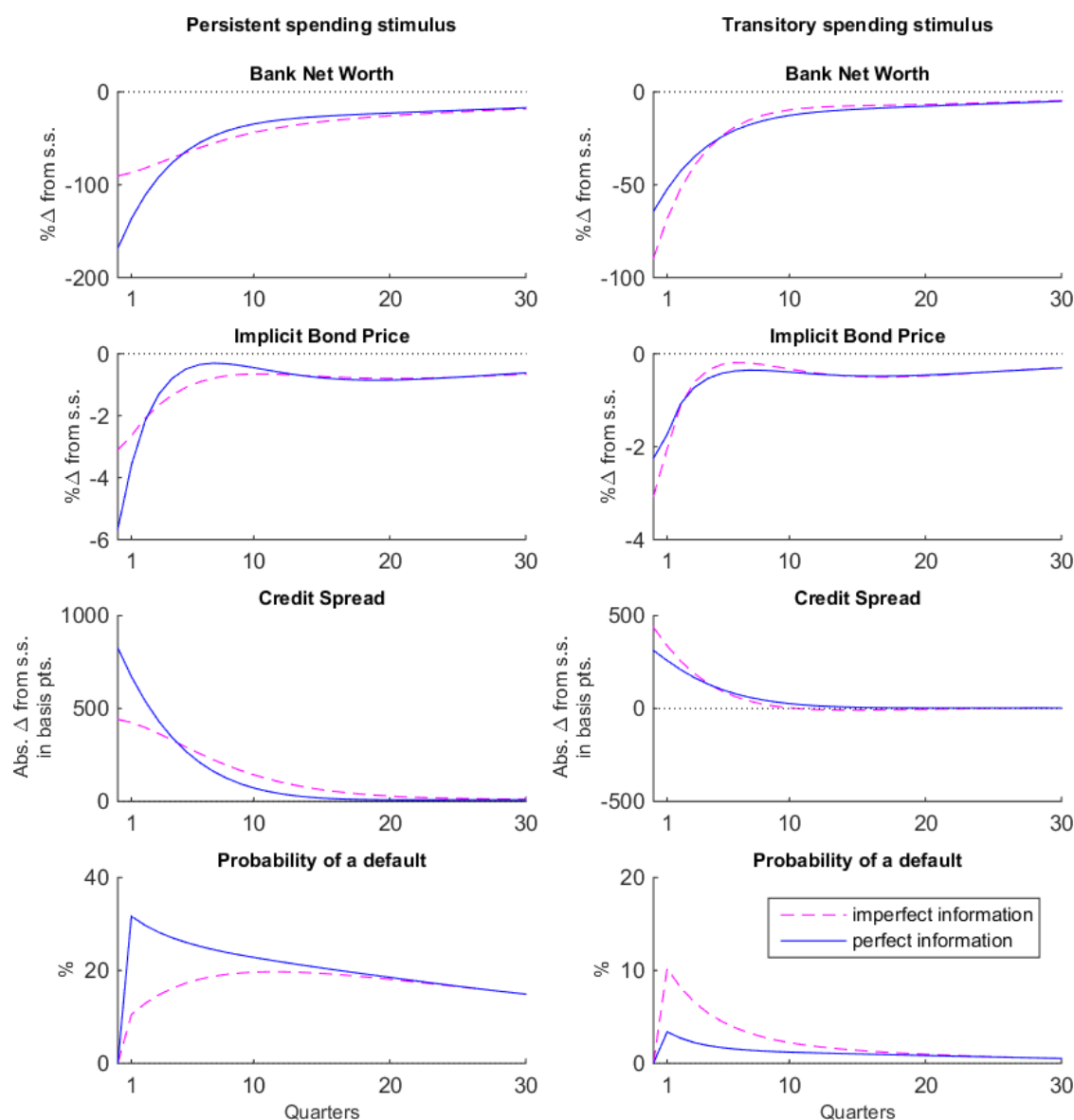


Figure 2.11: Financial effects of using a fiscal stimulus to counteract a negative capital quality shock



The difference in the variation of credit spread from perfect information to imperfect information scenario is near 385 basis points and the probability of default, in $t + 1$, under imperfect information is near 21 percentage points below the perfect information scenario. Investment falls on crisis impact but benefits from the gap in credit spread created by the distortion in information. After approximately three years, the decline in consumption gets larger than the fall in investment due to a higher expected future tax burden which more than offsets the initial output gain from the additional government spending. The mechanism that links expected fiscal

deficits, financial frictions and output effects was already explained in the previous section.

When the government resorts to a transitory spending stimulus to counteract the crisis, there is an initial relative output loss (until $t + 7$) compared to the perfect information case. This emerges from the agents' learning process about the nature of the shock, as they address some probability for a persistent shock and anticipate the fiscal costs of the government spending policy in accordance to their expectations. Probability of sovereign default hikes and as agents evolve in the learning process and get clear about the nature of the fiscal shock they anticipate the slow down in credit spreads associated with the true upcoming transitory fiscal deficits, leading to an improvement in bank leverage, borrowing costs and investment which, in turn, lead to a relative improvement of output dynamics compared with perfect information.

The previous section shown the advantage of using a transitory rather than a persistent spending stimulus, given the same information (im)perfection level. This section brings additional light to the results. Table 2.4 provides the accumulated output response during the events of this exercise for the two types of spending policy and for different information assumptions. The result that emerges is that transitory government spending is less costly for any given information assumption. In fact, at $t + 1$, when the fiscal stimulus is implemented, only transitory spending is able to improve the accumulated response of output, even under imperfect information. For a high degree of imperfect information ($\nu = 0.01$) the impact of a financial crisis in the economy ($t + 0$) is the same disregarding the nature of the spending package to be implemented – due to the severe distortions caused by information frictions agents anticipate higher deficit financing costs when spending is transitory and lower costs when spending is persistent. Although, the accumulated output response by the end of 30 periods indicates a clear advantage of the use of transitory spending rather than persistent, translated not only in lower accumulated output losses but also in lower probability of sovereign default.

2.4 Conclusion

Most DSGE models with financial frictions used to study the effects of fiscal policy assume that agents are fully aware of the composition and the duration of budgetary changes and its deficit implications. Evidence reveals that difficulty in distinguishing permanent from temporary changes in fiscal policy is a major source of fiscal policy uncertainty (*e.g.*, Baker et al., 2016; Hollmayr and Matthes, 2015). In most of the countries that suffered the European sovereign debt crisis, the deficit financed

Table 2.4: Output response and fiscal stimulus after a financial crisis						
Nature of fiscal policy	ν	$t + 0$	$t + 1$	$t + 5$	$t + 30$	$\max(P_{df})$
P	0.01	-3.56	-4.03	-24.09	-100.18	19.5%
T		-3.56	-3.41	-20.74	-44.97	10.4%
P^*	0.05	-3.57	-4.06	-24.29	-100.22	19.7%
T^*		-3.53	-3.37	-20.56	-45.06	10.2%
P	1	-4.89	-6.51	-35.50	-91.41	27.1%
T		-2.85	-2.33	-16.40	-48.64	4.6%
P	10	-6.14	-7.73	-38.21	-87.79	31.4%
T		-2.69	-2.19	-16.07	-49.08	3.4%
P	PI	-6.18	-7.75	-38.24	-87.73	31.6%
T		-2.69	-2.18	-16.06	-49.08	3.4%

Notes: ν denotes the signal-to-noise ratio; P stands for persistent government spending and T for transitory government spending; PI denotes the perfect information case; and $*$ identifies the benchmark imperfect information used in the analysis

fiscal response to counteract the 2007-2008 global financial crisis was undertaken by changes in highly persistent public expenditure components (Von Hagen, 2013). Apparently, financial markets reacted rather slowly to the information about policies that harmed fiscal positions in such countries. As soon as the fiscal solvency alarms triggered, markets became very sensitive to fiscal indicators, overreacting to fiscal news and noise (De Grauwe and Ji, 2012). This paper examines the macroeconomic and financial effects of a government spending stimulus when agents cannot observe if the shock occurs in the persistent (akin to rigid) or transitory spending component. Instead, agents learn about the nature of the shock over time by monitoring total government spending and a signal about the persistent component and use a Kalman filter to disentangle persistent from transitory changes in government expenditure. The modeling strategy resorted to a DSGE model with financial intermediation, as it allows to explicitly introduce a sovereign risk premium to assess the importance of the transmission of fiscal policy in this context and, as highlighted by numerous examples in the literature (*e.g.*, Corsetti et al., 2013; van der Kwaak and van Wijnbergen, 2014; Kirchner and van Wijnbergen, 2016; Bocola, 2016), at the end of 2009 domestic government bond holdings in the euro-area peripheral countries such as Greece, Italy, Portugal and Spain was equivalent to 93 percent of banks'

total equity, leading this way to a severe disruption of financial intermediation and a substantial increase in the borrowing costs of firms during the 2009-2011 sovereign debt crisis.

Incorporating imperfect information regarding government spending composition into an otherwise typical New Keynesian DSGE model with financial frictions amplifies the impact output multiplier of a persistent debt financed government spending shock. Agents do not fully anticipate the fiscal costs of the government spending policy so the rise in expected interest rates and credit spreads, through the associated tightening of bank balance sheet constraints and intermediary balance sheet adjustments, are limited. As a consequence of the smaller rise in borrowing costs, the demand for capital, and thus investment, is less crowded out and output expands further. Although the impact multiplier is higher, as agents learn about the true nature of the spending shock, the expectations about persistent debt financed deficits are adjusted and reflected in credit spreads leading to a worst output response that under perfect information. Cumulative output responses to a persistent government spending shock are lower with imperfect information than with perfect information. The results suggest that, for any degree of information, less persistent spending policies – spending policies that imply less taxation in the future – are more efficient in counteracting a crisis as they imply lower output losses. The paper also explores a pure expectation channel through considering a fiscal noise shock. It is shown that non-fundamental fiscal shocks have business cycle effects due to the interaction of banks' balance sheet adjustments, leverage constraints and the expectation of future debt financed fiscal deficits.

The analysis made in this paper provides a possible support to the evidence why, on one hand, the macro-financial reaction of an economy to fiscal policies is sometimes delayed and sluggish and, on the other hand, what are the consequences when it reacts to noise. The analysis supports the notion that agents have limited information about the true nature of fiscal shocks composition and need to learn about it to form expectations regarding the future debt and deficit implications. Reducing uncertainty and improving information about fiscal policy helps to clear expectations about fiscal outcomes which, in turn, improves economic outcomes, welfare and reduces sovereign risk. A limitation of the framework used in the analysis is that it does not internalize the reaction volatility of markets to fiscal policies: it is important to consider a threshold when markets start to overreact to fiscal indicators and to fiscal news or even noise. Another natural extension of this research is to consider a more rich taxation structure, and to assess how the availability of distortionary taxation may amplify the expectation channel embedded in this model.

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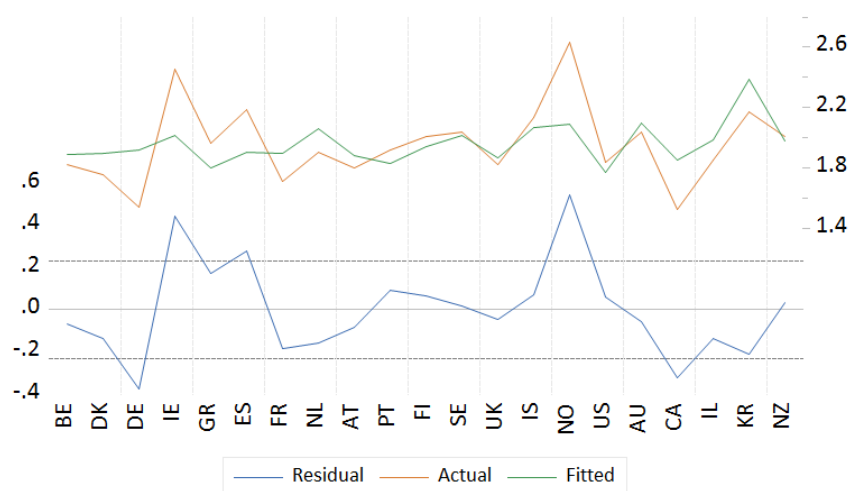
Appendix

2.A Supplementary material

Table 2.5: Dif-in-dif: Std. Dev. for 7 non-crisis euro-area countries

Variable	2007-08	2009-11
Real gdp growth	2.8	2.4
Total expenditures	0.6	1.4
<i>social benefits</i>	<i>0.4</i>	<i>0.8</i>
<i>compensations</i>	<i>0.1</i>	<i>0.1</i>
<i>interest</i>	<i>0.1</i>	<i>0.2</i>
Primary balance	0.4	0.6
Share of struct. balance	59.0	42.5
Debt ratio	4.3	1.8
Sample: AT, BE, FI, FR, DE, LU, NL		

Figure 2.12: Residuals from debt-limit regression (full sample)



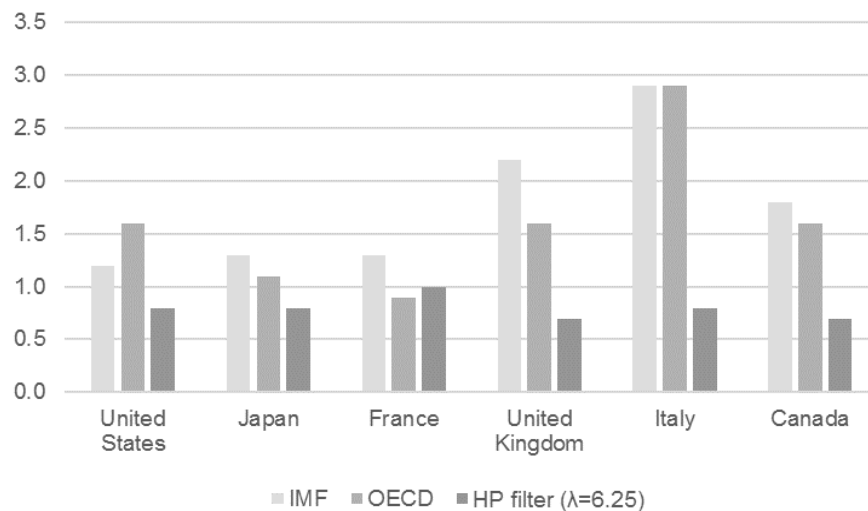
Chapter 3

Imperfect Output Gap Information in Optimal Fiscal and Monetary Policy

3.1 Introduction

The aim of this paper is to study the implications of imperfect information on output gap for the conduct of fiscal and monetary policy. Policymaking is inevitably conducted under uncertainty about the state of the economy. The economic cycle is typically measured by the output gap and relies on potential output, which is not observable, hence it is estimated on the basis of different models and assumptions. The estimates are surrounded by a high degree of uncertainty given that they usually entail large revisions, instability of output gap signs and corrections for distant periods in the past (Bundesbank, 2014). Orphanides (2001) illustrates this problem by showing that the standard deviation of the first revision of the US output gap is 0.66 percent, compared to a standard deviation of the previous output gap vintages of 1.78 percent, which implies that more than 35 percent of the fluctuations in the preliminary data may be due to measurement error. Coenen et al. (2005) and Giannone et al. (2012) examine the properties of data revisions for euro-area macroeconomic variables and show that real variables, such as real GDP or industrial production, are also often and sizeably revised. Likewise, the observed output contributes to output gap revisions as real-time data is subject to a considerable amount of measurement error. Figure 3.1 shows the mean absolute revisions to the initial estimates of output gap made by the IMF and the OECD compared with an HP filter for the period 1998-2010.

Figure 3.1: Mean of absolute revisions to the initial estimates for the output gap between 1998 and 2010 (*percentage points*)



Source: Bundesbank (2014)

There is a significant literature that studies the implications of imperfect information about output gap for the conduct of monetary policy. Orphanides (2001) shows that the output gap measurement errors lead to a significant deterioration of feasible policy outcomes and cause efficient policies (in a simple Taylor rules framework) to be less active in stabilizing economic fluctuations. Orphanides and Williams (2002) suggest that underestimating the unreliability of real-time estimates of the unobservable natural rates, such as the potential output, may lead to policies that are very costly in terms of the stabilization of the economy. Ehrmann and Smets (2003) argue that output-gap mismeasurement may pose a serious problem for the correct assessment of the state of the economy and for the conduct of monetary policy, concluding that under imperfect information about potential output, it is optimal to appoint a more conservative central bank that puts less weight on output gap. Svensson and Woodford (2003) note that there is an important role of the estimate of current potential output for optimal monetary policy, and show that the proper weight to put on economic indicators under an optimal policy rule depend on how noisy are those indicators. In line with Ehrmann and Smets (2003), using estimates based on euro-area real-time data Neri and Ropele (2012) conclude that, with imperfect information about the state of the economy, the estimated monetary policy rule becomes more inertial and less aggressive towards inflation and the central bank faces a more severe trade-off in the stabilization of inflation and the output gap.

Thus far, this body of work examined the implications of imperfect information on monetary policy disregarding fiscal policy. However the uncertain output gap that characterizes the economic environment and motivates these analyses is assuming a greater importance for fiscal policy and, in addition the interaction between fiscal and monetary policy cannot be neglected. As a matter of fact, estimates of the output gap play an important role in the analysis of public finance and in the context of budgetary rules, particularly in Europe since the Stability and Growth Pact is based on cyclically-adjusted variables¹ and the UK adopted a cyclically-adjusted target for public finances. Although targeting cyclically-adjusted public finances has the advantage of allowing countercyclical fiscal policy, while ensuring fiscal sustainability, such targeting rely on accurate estimates of the output gap – which introduce a high degree of uncertainty in the conduct of fiscal policy.² Kempkes (2014) argues that there is a real-time negative bias in estimated output gaps for EU-15 countries and this bias can lead to considerable debt-ratio hikes if cyclically-adjusted borrowing limits are in place, given that the real structural balance should figure worst than the one estimated in real-time. The misperception of output gap affects also fiscal policy via monetary policy, even when the macroeconomic stabilization role of the former is limited to ensure a solvent fiscal position. The use of the interest rate by a central bank as described in the literature of optimal monetary policy has an impact on the public debt through the debt service which, in the presence of incomplete information, may trigger distortionary effects due to the use of fiscal instruments to ensure that debt follows a sustainable path, or generate a misperception about fiscal space. It would thus be useful to examine how uncertain output gap shapes optimal fiscal and monetary policy since it has clear policy implications.

The contribute of this paper is to provide a bridge between the literature on optimal monetary policy under imperfect information and the literature on joint monetary-fiscal optimization. Accordingly, the analysis is conducted by extending the framework of optimal monetary policy under uncertain potential output of Ehrmann and Smets (2003). Public debt, government spending and distortionary income taxation are introduced in a standard New Keynesian model of a closed economy with price rigidity where benevolent social welfare is derived from the utility of the representative agent. Potential output is not observed so policymakers

¹See Mourre et al. (2013) for the method applied to the EU fiscal framework.

²Andersen (2013) uses a model with signal extraction to analyze how the measurement problem inherent to the structural balance budget affects budget targeting. The author concludes that, due to the noise in the indicator, a strict targeting of the structural budget balance leads to excessive policy responses to transitory influences, and thus causes excessive policy activism in contrast to the underlying “smoothing” aim motivating fiscal policy targets.

and private agents need to estimate it on the basis of previous period output and current inflation. This framework is similar to introducing imperfect information to the monetary-fiscal optimization framework of Leith and Wren-Lewis (2013), that builds on the work of Benigno and Woodford (2004) and Schmitt-Grohé and Uribe (2004). The model without income taxation as a fiscal instrument is also considered in order to assess the welfare and economic stabilization effects of using such policy instrument. Throughout the paper, fiscal and monetary policy are conducted under full coordination for the sake of comparability with the mentioned literature on optimal monetary policy so, in practice, one could abstract that there are two policy agencies. The analysis focuses on the implications of imperfect information for optimal commitment and optimal discretionary policies leaving, for further research, the use of simple rules. The solution technique is closely related to Svensson and Woodford (2003) who derive general formulas for computation of optimal policy and filtering in forward looking models. Certainty equivalence (optimal policies are independent of additive uncertainty) and the separation principle (the estimation problem can be separated from the control problem) hold, as the analysis is performed in a linear-quadratic framework where the policymakers and the private sector know the structure of the economy being modeled.

The findings of this paper can be summarized as follows. The misperception about the true output gap in a joint fiscal-monetary optimization framework amplifies the welfare costs of economic stabilization policies, both under commitment and discretion. Monetary and fiscal instruments are set optimally since certainty equivalence holds, but react to misperceived shocks with consequences for economic stabilization – after a cost-push shock the income tax rate cut is lower than that under perfect information, the drop in government spending is higher and monetary policy turns active raising interest rates under commitment. This explains the higher welfare costs of imperfect information under commitment, given that a rise in the interest rate has a negative effect on private consumption and the amplitude of changes in fiscal instruments (lower government spending and higher taxation) lead debt to a new steady-state, where the debt-to-GDP is significantly lower in absolute terms than under perfect information. Some robustness tests suggest that, if income taxation is considered, when the degree of price rigidity rises the welfare losses increase under imperfect information, contrarily to what happens if there is perfect information.

The remainder of this paper is organized as follows. Section 2 outlines the model and presents the calibrated parameters. In section 3 the certainty-equivalent optimal fiscal-monetary policy is characterized both under commitment and under

discretion. Section 4 proceeds with the analysis of optimal policy simulations under perfect and imperfect information. Some robustness tests are presented in section 5. Finally, section 6 concludes.

3.2 The Model

The model is a simple version of the new Keynesian models which have been used in recent research on optimal monetary and fiscal policy. The structure of the economy is described by a log-linearized Phillips curve, an expectational IS curve, the national income identity, and an equation explaining the evolution of debt (*e.g.*, Benigno and Woodford, 2004, Kirsanova and Wren-Lewis, 2012, and Leith and Wren-Lewis, 2013). The government is assumed to have access to public spending and distortionary income taxes as policy instruments.³ The model used throughout the paper distinguishes from the optimal fiscal policy literature due to the inclusion of imperfect information in the policymaking process.

3.2.1 The structure of the economy

The economy is populated by a continuum of infinitely-lived individuals, who seek to maximize the objective function,

$$E_t \left\{ \sum_{s=0}^{\infty} \beta^s [u(C_{t+s}) + w(G_{t+s}) - v(N_{t+s})] \right\}, \quad (3.1)$$

subject to a standard intertemporal budget constraint, where C_t , G_t , and N_t denote, respectively, private consumption, public consumption and labor supply. The expectation operator is given by E_t and β is the household discount rate. After linearizing the first order conditions from the household problem we obtain the Euler equation for the economy

$$c_t = E_t \{c_{t+1}\} - \sigma \left(\hat{i}_t - E_t \{\pi_{t+1}\} \right), \quad (3.2)$$

where c_t , π_t and $\hat{i}_t$ are (in log deviations from zero inflation steady-state) private consumption, inflation rate and nominal interest rate, respectively. The parameter σ represents the inverse of the intertemporal elasticity of substitution of expenditure.

The unit-continuum of monopolistically competitive firms in the economy set prices optimally according to the Calvo (1983) mechanism, with $(1 - \gamma)$ of firms changing price in a given period, with γ being the probability that the price remains

³Appendix 3.B contains a more detailed derivation of the model and its microfoundations.

unchanged. Aggregation across prices, and considering a steady-state with zero inflation yields the following expectational Phillips curve:

$$\pi_t = \beta E_t \{\pi_{t+1}\} + \kappa_y (y_t - y_t^n) - \kappa_g (g_t - g_t^n) + \kappa \frac{\bar{\tau}}{1 - \bar{\tau}} \hat{\tau}_t + \kappa \eta_t, \quad (3.3)$$

where y_t is real output and y_t^n represents the potential level of output, which corresponds to the equilibrium level of output if prices were fully flexible, and for the sake of simplicity is considered as an exogenous shock in this model. g_t^n is the natural/efficient government spending and it is a function of y_t^n as it is shown in Appendix 3.B. $\hat{\tau}_t$ is the percentage point deviation of the income tax rate from its steady-state value $\bar{\tau}$. The parameters κ , κ_y and κ_g are defined as

$$\kappa = \frac{(1 - \gamma\beta)(1 - \gamma)\varphi}{\gamma(\varphi + \epsilon)}; \kappa_y = \frac{\kappa}{\varphi} \left[1 + \frac{\varphi}{\sigma(1 - \theta)} \right]; \kappa_g = \frac{\kappa\theta}{\sigma(1 - \theta)}.$$

Here, $\varphi = \frac{v_n}{v_{nn}} \frac{1}{N}$ is the elasticity of labor supply. The elasticity of substitution between goods of different varieties is given by ϵ , which is considered stochastic in order to allow mark-up shocks,⁴ *i.e.* the pure cost-push shock given by η_t . θ is the steady-state government spending share on output.

The government issues nominal debt B_t and collects taxes (constant lump-sum taxes T and distortionary income taxes with tax rate τ_t) in order to buy goods G_t , pays a subsidy ς , and pays the principle and interest on its existing debt. The subsidy, financed with lump-sum taxes, ensures that there are no solvency problems in the efficient equilibrium, as it offsets monopolistic and tax distortions in steady-state.⁵ The linearized government budget constraint can be written as

$$\hat{b}_{t+1} = \hat{i}_t + \frac{1}{\beta} \left[\hat{b}_t - \pi_t + \frac{\theta}{\psi} g_t - \frac{\bar{\tau}}{\psi} (\hat{\tau}_t + y_t) \right], \quad (3.4)$$

where $\hat{b}_t$ is the log-linearized real government debt and ψ is the steady-state ratio of debt to output. In steady-state, the income tax rate is given by $\bar{\tau} = (1 - \beta)\psi + \theta$. The model closes with the log-linearized national income identity,

$$y_t = (1 - \theta) c_t + \theta g_t. \quad (3.5)$$

The following stochastic processes for the potential output and cost-push shocks are assumed:

⁴See, for instance, Kirsanova and Wren-Lewis (2012) and Beetsma and Jensen (2004).

⁵In Appendix 3.B one can see further the role of such subsidy. See also, for example, Gali and Monacelli (2008).

$$\begin{aligned}y_{t+1}^n &= \rho_y y_t^n + \varepsilon_{t+1}^y, \\ \eta_{t+1} &= \rho_\eta \eta_t + \varepsilon_{t+1}^\eta,\end{aligned}$$

with each of the two shocks is independent and serially uncorrelated with variances σ_y^2 and σ_η^2 respectively, and for $x \in [y, \eta]$ $0 \leq \rho_x < 1$.

Following Kirsanova and Wren-Lewis (2012) and Leith and Wren-Lewis (2013), using a second-order approximation of the aggregate utility function, it is shown, in Appendix 3.C, that the model-consistent social welfare function can be expressed as

$$\mathbf{W}_t = -\frac{1}{2}E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \lambda_\pi \pi_t^2 + \lambda_y (y_t - y_t^n)^2 + \lambda_c (c_t - c_t^n)^2 + \lambda_g (g_t - g_t^n)^2 \right\}, \quad (3.6)$$

where coefficients $\lambda_\pi = \frac{\varphi\epsilon}{(\varphi+\epsilon)\kappa}$, $\lambda_y = \frac{1}{\varphi}$, $\lambda_c = \frac{(1-\theta)}{\sigma}$, and $\lambda_g = \frac{\theta}{\sigma}$ are determined by the parameters of the model. This quadratic approximation to social welfare is obtained assuming that there is a constant subsidy ς that eliminates distortions caused by monopolistic competition and distortionary income taxation in steady-state.

3.2.2 Information

In cooperation, the monetary and fiscal policymakers jointly set their instruments $\{i_t, g_t, \tau_t\}$ to maximize the welfare function (3.1), which implies the minimization of the expected discounted sum of period loss functions

$$\min \frac{1}{2}E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \lambda_\pi \pi_t^2 + \lambda_y (y_t - y_t^n)^2 + \lambda_c (c_t - c_t^n)^2 + \lambda_g (g_t - g_t^n)^2 \right\},$$

subject to equations (3.2), (3.3), (3.4) and (3.5) which describe the economy. Following Svensson and Woodford (2003) and the notation used by the authors, the model can be written in the state-space form:

$$\begin{bmatrix} X_{t+1} \\ x_{t+1|t} \end{bmatrix} = \mathbf{A}^1 \begin{bmatrix} X_t \\ x_t \end{bmatrix} + \mathbf{A}^2 \begin{bmatrix} X_{t|t} \\ x_{t|t} \end{bmatrix} + \mathbf{B} \iota_t + \begin{bmatrix} u_{t+1} \\ 0 \end{bmatrix},$$

where X_t is a vector of n_X predetermined variables, x_t is a vector of n_x forward-looking variables, ι_t is a vector of the policymakers' n_i policy instruments, u_t is a vector of n_X i.i.d. shocks with mean zero and covariance Σ_{uu} , and $\mathbf{A}^1$, $\mathbf{A}^2$ and $\mathbf{B}$

are matrices of appropriate dimension. For any variable ϑ_t , the index $t+i|t$ is used to denote the rational expectation of ϑ_{t+i} , given the information available at time t .

In this paper it is assumed that information is symmetric, which means that the policymakers and the private sector have the same information set, either perfect or imperfect. When information is perfect, agents observe output, inflation and potential output, which is sufficient to perfectly derive the structural shocks in this economy. Imperfect information arises when agents do not observe potential output directly, although they do observe last period output and inflation. Agents will face a signal extraction problem in trying to distinguish cost-push shocks from potential output shocks in equation (3.3), giving rise to output gap uncertainty. As Ehrmann and Smets (2003) exemplify, this assumption can be rationalized by assuming that each individual price-setting firm observes its own idiosyncratic productivity and cost-push shock, but not that of other firms, leading private sector expectations as a whole to hardly incorporate aggregate productivity and cost-push shocks.

Under imperfect information, at time t , agents use a Kalman filter to estimate the state of the economy X_t , having the information set represented by a vector Z_t of observable variables, in this case consisting of last quarter output (y_{t-1}^o) and current inflation (π_t^o), which are noisy indicators of X_t and x_t according to the mapping:

$$Z_t = \mathbf{D}^1 \begin{bmatrix} X_t \\ x_t \end{bmatrix} + \mathbf{D}^2 \begin{bmatrix} X_{t|t} \\ x_{t|t} \end{bmatrix} + v_t,$$

where $\mathbf{D}^1$ and $\mathbf{D}^2$ are matrices of appropriate dimension and v_t is the vector of measurement errors.

As originally emphasized by Pearlman et al. (1986), the assumption of imperfect information poses rather complex problems in terms of the signal-extraction problem agents need to solve, as the model dynamics is also driven by forward-looking variables. Svensson and Woodford (2003) show a modified version of the Kalman filter, used in this paper, which takes into account this circularity. These authors also show that, since the loss function is quadratic and the structural equations are linear, certainty equivalence holds, in the sense that optimal policy reactions to estimated states of the economy are independent of the degree of uncertainty. When information is symmetric, as in this paper, the separation principle holds, in the sense that estimation of the state of the economy is independent of optimal policy and the information structure. For the derivation of the optimal policies under commitment and discretion refer to Svensson and Woodford (2003) and Ehrmann and Smets (2003), as this paper uses the same notation.

3.2.3 Calibration

The model frequency is assumed to be quarterly for comparability with the literature on optimal fiscal and monetary policy. Following Ehrmann and Smets (2003) and Kirsanova and Wren-Lewis (2012) the household discount rate is set $\beta = 0.99$, which yields a steady-state real rate of interest of approximately 4% per year. The steady-state share of government expenditure in output, θ , is 0.25, the elasticity of intertemporal substitution σ is taken as 0.5 and the Calvo parameter γ is set as 0.75, which implies that prices are set on average once a year. The elasticity of demand is given by $\epsilon = 5$, and the elasticity of labour supply is taken as $\varphi = 2$. The baseline calibration for the steady-state debt to output ratio, ψ , is 0.1, although alternative scenarios are considered. This calibration implies a steady-state tax rate of $\bar{\tau} = 0.251$. Some robustness tests are made to the steady-state debt ratio and the Calvo parameter to validate the results.

The cost-push shock is calibrated following Ehrmann and Smets (2003) and the estimations therein and the potential output shock is set so that the perceived and actual output gap take at least 2 years to converge, in order to capture the data revisions process. Both shocks are set as an AR(1) process. The cost-push shock is calibrated as $\rho_\eta = 0$ and $\sigma^2(\epsilon^\eta) = 0.42$ and the potential output shock as $\rho_y = 0.95$ and $\sigma^2(\epsilon^y) = 0.013$. Finally, following the authors, the measurement errors of output defined in the next section assume a variance of about $\sigma^2(z, v) = 0.06$, translating the persistent revisions in real GDP while there is no measurement error in current inflation. Some robustness tests are made to the steady-state debt ratio and the Calvo parameter to validate the results.

3.2.4 Optimal instrument rule

When the policymaker can commit to its future policy actions the optimal policy rules will be a linear function of the optimally estimated state vector of the economy and will also depend on a set of Lagrange multipliers that are associated with the forward-looking variables:

$$\iota_t = F_c X_{t|t} + \Phi \Xi_{t-1},$$

where Φ is the vector of reaction coefficients to the Lagrange multipliers Ξ_{t-1} associated with the forward-looking variables. In this framework, optimal commitment policy is time inconsistent in its control of both inflation and debt, as shown by Leith and Wren-Lewis (2013). These authors provide that a negative value of the Lagrange multiplier associated with private consumption, Ξ^c , is equivalent to a

Table 3.1: Optimal policy feedback coefficients: commitment and discretion

Fiscal instrument: g						
	η_t	y_t^n	y_{t-1}	b_t	Ξ_{t-1}^π	Ξ_{t-1}^c
<i>Commitment</i>						
i_t	0.013	-0.094	0	-0.003	-0.009	-1.119
g_t	-0.001	1.010	0	-0.005	0.001	-0.090
<i>Discretion</i>						
i_t	0.035	-0.080	0	-0.011		
g_t	-0.041	1.152	0	-0.083		
Fiscal instruments: g and τ						
	η_t	y_t^n	y_{t-1}	b_t	Ξ_{t-1}^π	Ξ_{t-1}^c
<i>Commitment</i>						
i_t	-0.001	-0.100	0	-0.0001	0.001	-1.146
g_t	-0.002	1.001	0	-0.0002	0.001	-0.103
τ_t	-2.669	-0.077	0	0.042	1.887	-3.696
<i>Discretion</i>						
i_t	0.062	-0.115	0	0.008		
g_t	-0.017	1.004	0	-0.002		
τ_t	-0.217	-0.677	0	0.369		

positive value of the Lagrange multiplier for debt, which indicates the incentive to reduce debt under optimal commitment policy. This incentive does not vanish over time because both multipliers follow a random walk. The intuition is that in any period there is a benefit from reducing debt through cutting interest rates and/or government expenditure in order to cut debt service costs. Although, such action entails an inflationary cost. While the gain of cutting debt is constant over time, the cost of reducing debt in the first period is smaller than in subsequent periods because, unlike for subsequent periods, inflation expectations have already been set. A policymaker who re-optimizes every period and, therefore, treats inflation expectations as given every period will face an incentive to unexpectedly lower debt in every period – the random walk under optimal commitment policy is therefore time inconsistent.

In the discretionary case optimal policy must be time consistent so the policymaker re-optimizes every period by taking the process of how private agents determine their expectations as given. The optimal policy rules will be a linear function of the optimally estimated state vector of the economy:

$$\iota_t = F_d X_{t|t}.$$

For the calibrated model, Table 3.1 reports the optimal feedback coefficients under commitment and discretion, when the fiscal policymaker has only g_t as instrument and when g_t and τ_t are available.

An important aspect that should be noted in Table 3.1 is that when income taxation is not available as policy instrument, the fiscal authority leaves the stabilization of the cost-push shock mostly to monetary policy, mainly because movements in g_t , in contrast to i_t , are costly as they induce higher welfare losses. When income taxation is available as fiscal instrument, monetary authority leaves the stabilization of the cost-push shock to the fiscal authority, since lower income taxes are more efficient at reducing inflation than higher interest rates because they act on the same margin as the distortionary cost-push shock (Kirsanova and Wren-Lewis, 2012). In the case of potential output shock, government spending is the instrument that assumes a primary role.

3.3 Optimal policy results

This section analyses the cooperative outcomes of optimal monetary and fiscal policy under perfect information (PI) and imperfect information (II) for macroeconomic stabilization purposes.⁶ Table 3.2 shows the value of the loss function for distinct informational assumptions and two combinations of fiscal policy instruments under commitment and discretionary policy.

Table 3.2: Optimal policy and the value of information

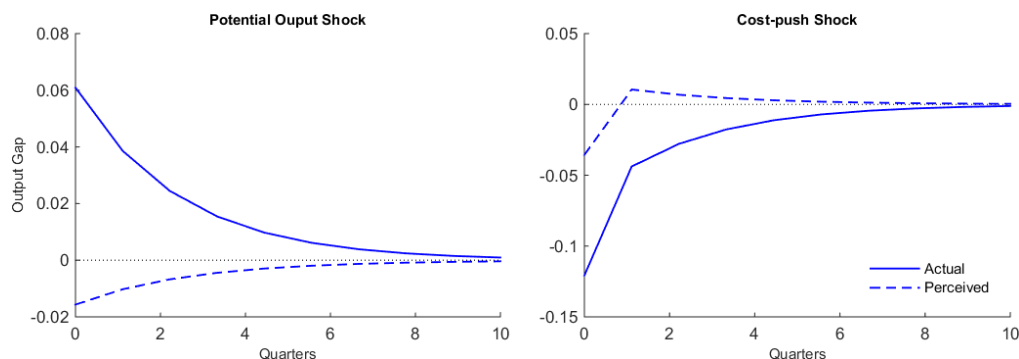
Instruments	information	Welfare Loss	
		<i>Commitment</i>	<i>Discretion</i>
i_t, g_t	PI	1.06	1.45
	II	6.26	6.73
i_t, g_t, τ_t	PI	0.14	1.34
	II	5.65	6.53

There is a considerable amount of loss that arises from imperfect information, both under discretion and commitment, in line with the results that consider only monetary policy (*e.g.*, Ehrmann and Smets, 2003). There is a clear observed value of commitment, which gains seem to be larger when income taxation is available and there is perfect information. When the fiscal policymaker has only government spending as policy instrument losses are higher. This is due to the fact that, in this

⁶See Appendix 3.D for a detailed analysis of the results under perfect information assumption.

framework, income taxes are more efficient at reducing inflation since they act on the same margin as the distortionary cost-push shock and also because there is loss in utility from reducing government spending. An interesting result that emerges is that when income taxation is available as an instrument, the cost of imperfect information is higher under commitment – the use of distortionary taxation as a fiscal instrument reduces the value of commitment under imperfect information.

Figure 3.2: Actual versus perceived output gap (discretion)



Following Ehrmann and Smets (2003), Figure 3.2 plots the response of the actual and perceived output gap to a negative potential output shock and a positive cost-push shock under imperfect information in the discretion case, revealing how persistent the prediction errors in the output gap may be. Under both shocks, policymakers observe a rise in prices and fall in output but, depending on the true shock it implies opposite responses from output gap: after a positive cost-push shock it is expected a fall in output gap; after a negative potential output shock the output gap should rise. Figure 3.2 suggests that the policymakers under-predict output gap after a potential output shock, persistently estimating it to be negative while the real gap is positive, while over-predict the output gap in response to a cost-push shock.

3.3.1 Imperfect information: solution under commitment

Under imperfect information (II) the policy instruments are set in an optimal way verifying certainty equivalence, as explained in the previous section. Nonetheless, the estimation of potential output generates misreading of the shocks which leads to higher welfare costs as a consequence of the use of policy instruments with imperfect information about the state of the economy. Differently from when optimal monetary policy is studied isolated, as in Ehrmann and Smets (2003) or Svensson

and Woodford (2003), when fiscal policy is considered the problem becomes more complex because different instruments must be set with distinct policy goals.

Figure 3.3 compares the impulse responses of optimal commitment policy to a positive cost-push shock under PI and II. Under II, optimal commitment policy amplifies the negative response of output gap to a positive cost-push shock, leading to less inflation and to the stabilization of debt at a higher level than the initial, but significantly lower than under PI. Due to imperfect information, in response to a positive cost-push shock policymakers assign some probability that this is actually a negative potential output shock. As a result the fiscal policymaker cuts government spending which helps the monetary policymaker to control the inflation, but with a higher welfare loss consequence and amplifying output-gap. When income taxation is available, the fiscal policymaker cuts the tax rate to directly offset the cost-push shock, but less than in PI due to the assigned probability that this may be a negative potential output shock. This misreading drives the policymaker to rise tax rate in the next period which leads to a faster convergence of debt to the new higher steady-state, but again lower than under PI. An interesting result is that when income taxation is available, imperfect information under commitment turns the monetary policy active in reaction to a probable negative potential output shock. This helps explaining higher welfare costs of imperfect information under commitment, given that a rise in interest rate has a negative effect on private consumption, a component of the utility derived social welfare.

When the economy is hit by a negative potential output shock the opposite occurs in terms of perception: policymakers assign some probability that this might be a positive cost-push shock. Figure 3.4 compares impulse responses of optimal commitment policy to a negative potential output shock under PI and II. Under II a negative potential output shock amplifies the positive output gap, generating more inflation than under PI. The fiscal policymaker cuts government spending partially due to the belief of some probability that this might be a positive cost-push shock, so output drops less than under PI and output gap gets higher. This generates inflation so the monetary policymaker rises interest rates, which leads debt to stabilize in a higher steady-state than under PI. When income taxation is available, the policymaker cuts tax rate instead of rising, due to the assigned probability of a positive cost-push shock. The monetary policymaker rises interest rates less than under PI, but the undercut in government spending and the wrongly cut in tax rate fuels a significantly higher debt under II.

Figure 3.3: IRF to a 1SE positive cost-push shock under commitment - perfect (PI) vs. imperfect information (II)

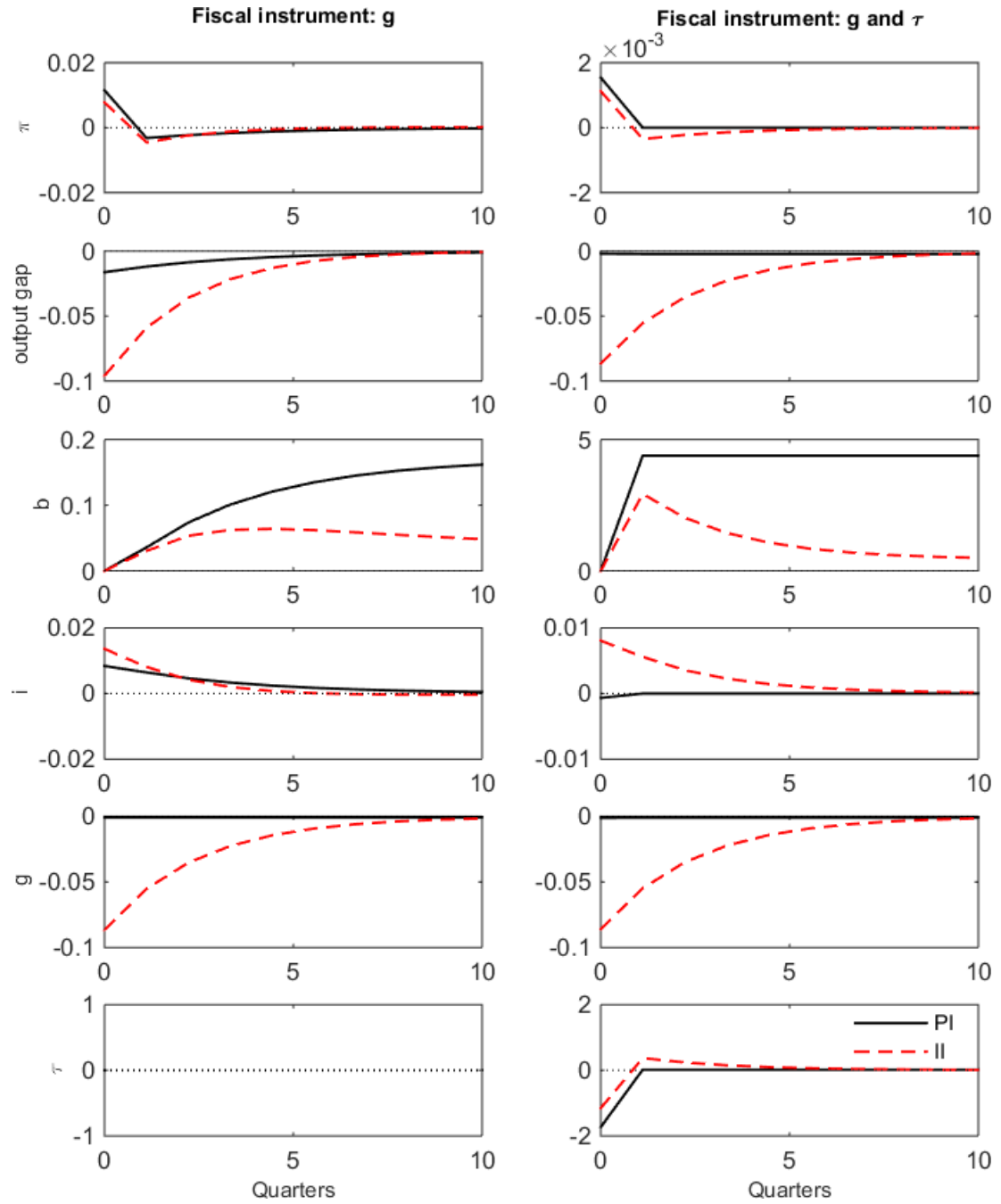
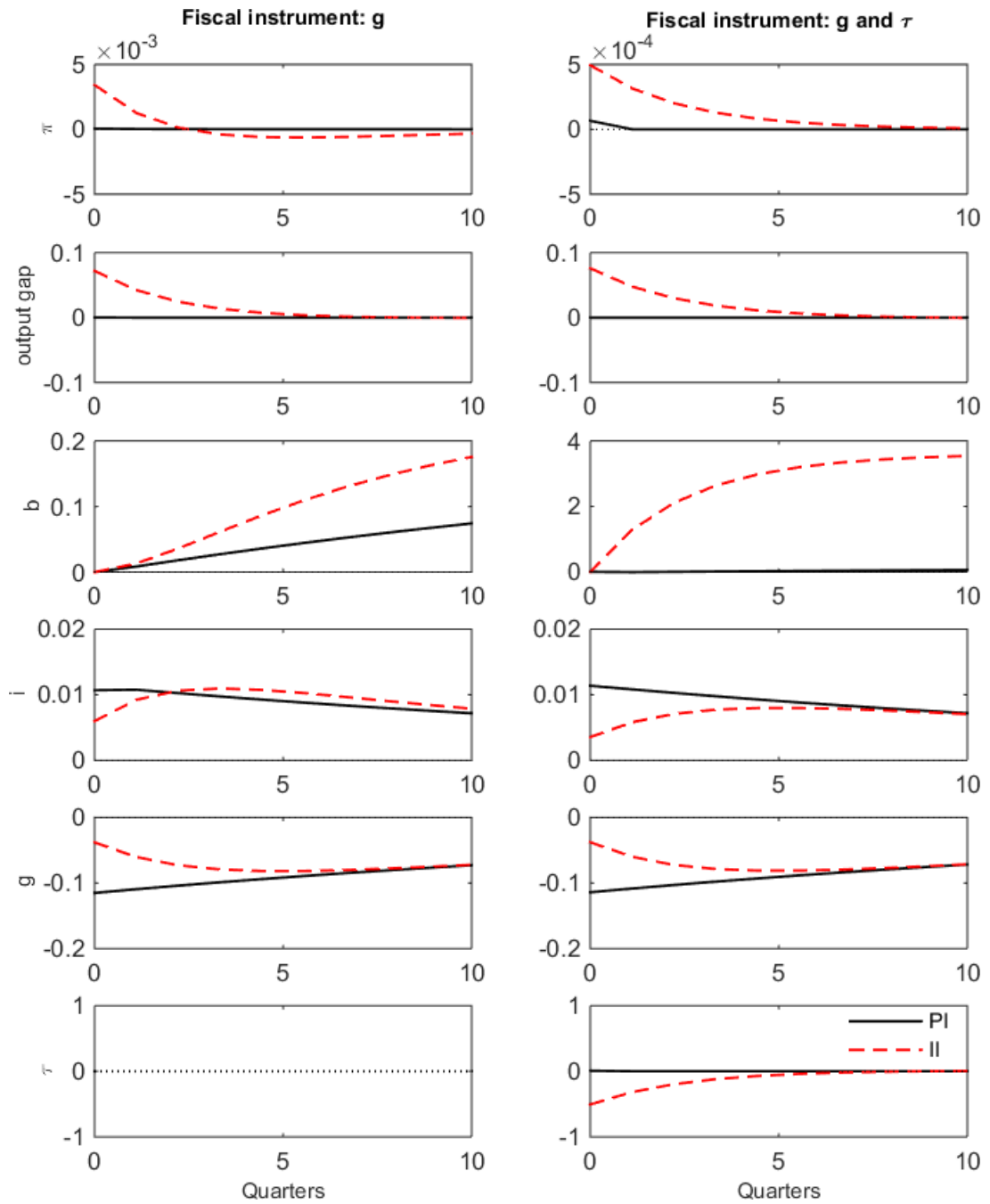


Figure 3.4: IRF to a 1SE negative potential output shock under commitment: perfect (PI) vs. imperfect information (II)



3.3.2 Imperfect information: solution under discretion

When policymakers optimize under discretion, the misperception of the output gap together with inflation and debt stabilization bias amplifies welfare losses.

Figure 3.5 compares the impulse responses of optimal discretionary policy to a positive cost-push shock under PI and II. The misperception of a deeper negative output gap generates less inflation, so the monetary policymaker still raises interest rates in the first period but marginally less than under PI. Under discretion fiscal policy is more proactive due to the debt stabilization bias, so the fiscal policymaker cuts government spending to control debt, but as the probability of a negative supply shock is considered, the policymaker cuts government spending by more than under PI. This fiscal reaction balances the effects of interest rate on debt in the first period and as the cut in government spending lasts longer, under II debt drops leading to a negative dynamics of convergence to the pre-shock ratio. The perceived negative output gap is deflationary, leading the monetary policymaker to cut interest rates in the next period which amplifies the negative effect on debt. When income taxation is available, the policymaker cuts the tax rate to address the positive cost-push shock, although, as it also considers the probability of a negative potential output shock, the tax cut is smaller than under PI and government spending cut is higher. Debt rises in period one because the effect of interest rate rise and tax rate cut is higher than the government spending cut in the previous period, which leads to a tax rate rise in period one to contain debt.

A negative potential output shock under II generates more inflation as output gap is higher than under PI. Figure 3.6 shows that since some probability of a positive cost-push shock is considered, optimal discretionary policy response of the monetary policymaker is to rise interest rates by more than under PI to contain inflation. A cut in government spending to contain debt that rises due to interest rates is smaller than under PI due to shock misperception. When income taxation is available, under II, the fiscal authority cuts the tax rate to contain the possibly positive cost-push shock, as under discretion the optimal feedback rule coefficient associated to cost-push shock is higher than the one associated with potential output shock (Table 3.1). The tax cut helps to contain inflation but generates a debt hike in the next period. The fiscal policymaker then rises tax rate to contain debt, but generates inflation so the monetary policymaker rises the interest rate for a longer period which, in turn, makes debt rise last longer.

Figure 3.5: IRF to a 1SE positive cost-push shock under discretion: perfect (PI) vs. imperfect information (II)

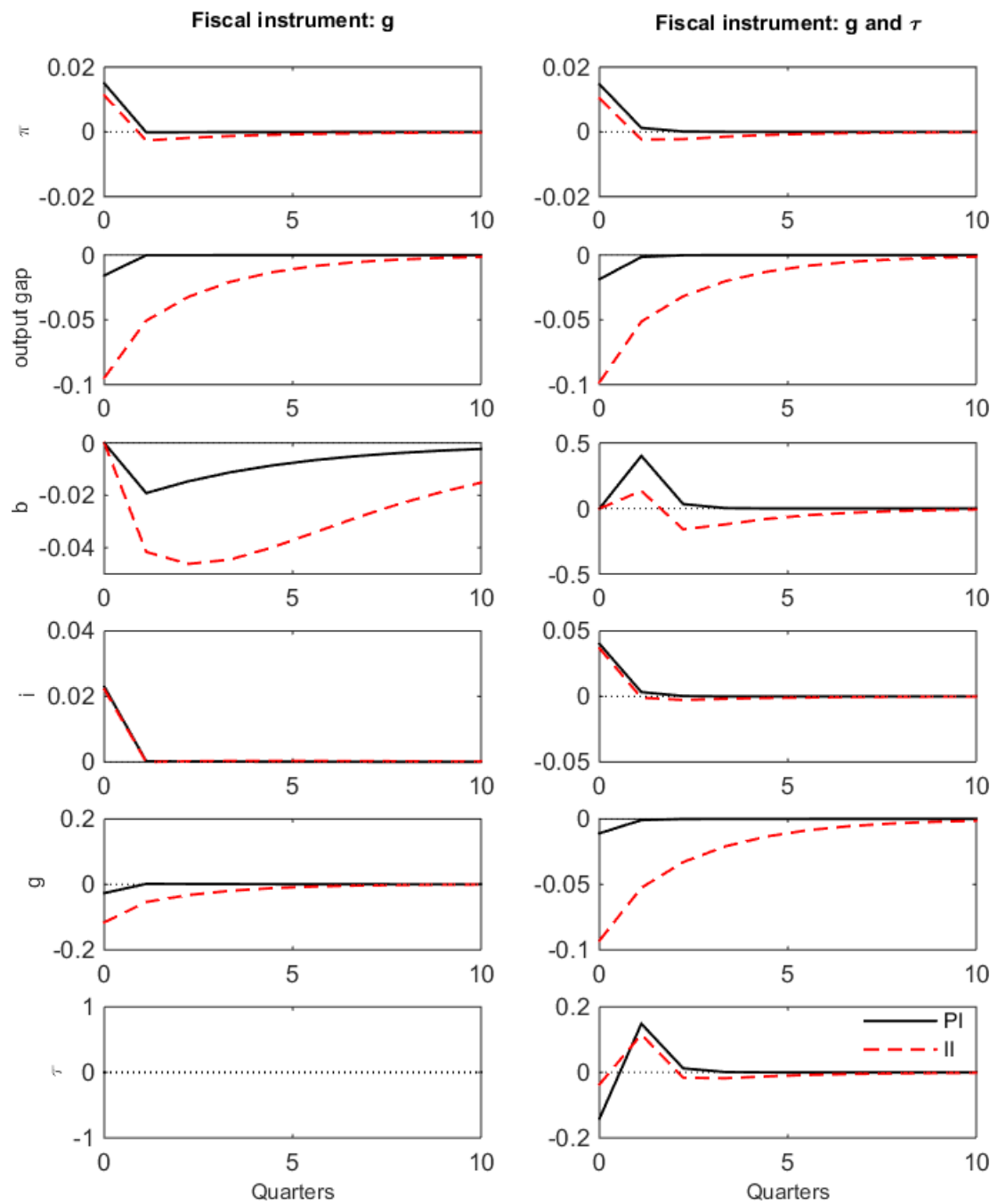
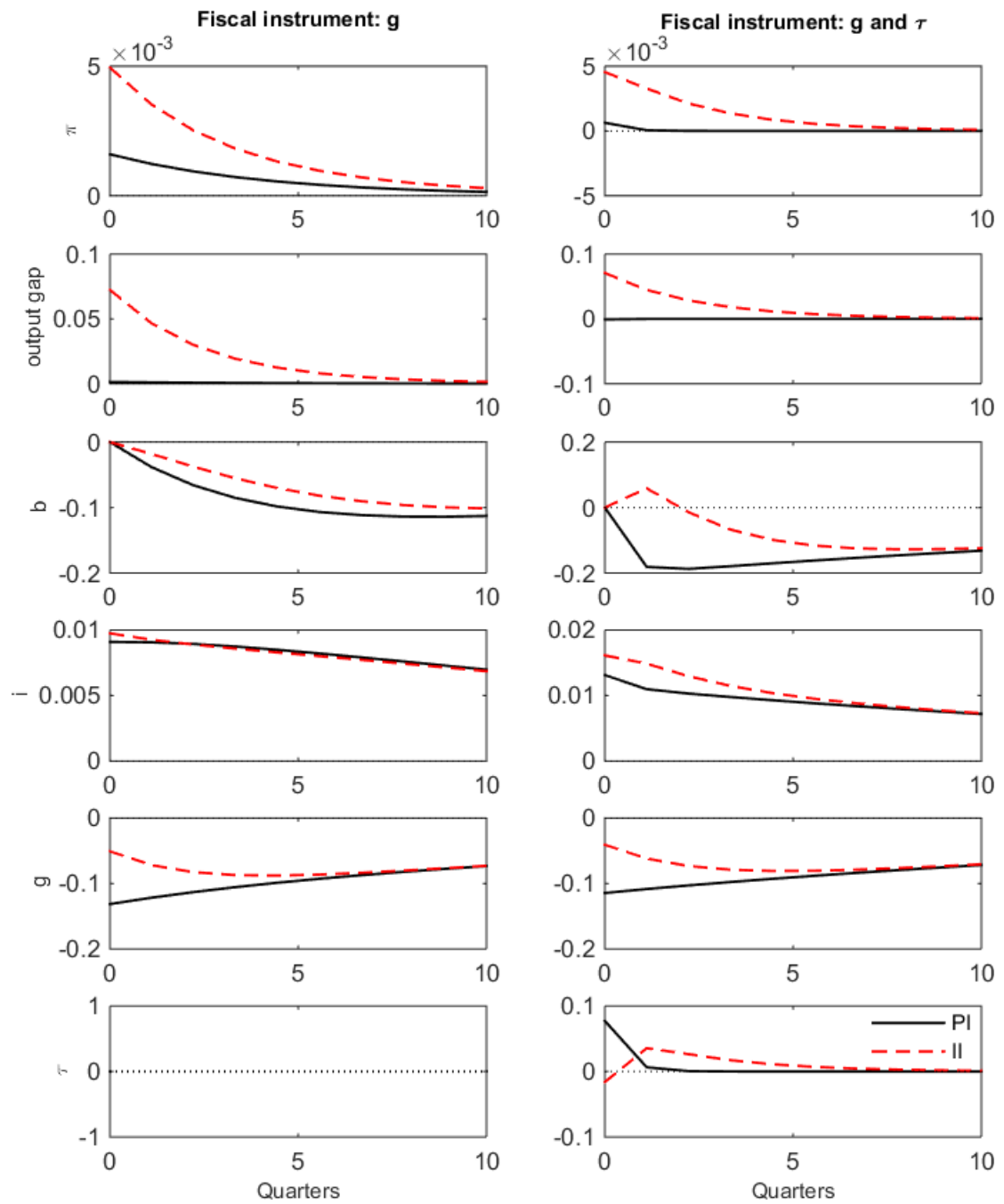


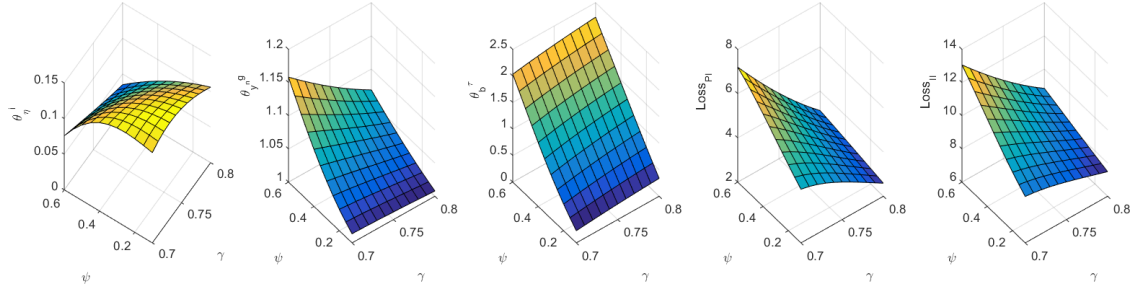
Figure 3.6: IRF to a 1SE negative potential output shock under discretion: perfect (PI) vs. imperfect information (II)



3.4 Robustness

This section analyses the robustness of results with respect to changes in selected parameters of the model, so it allows to identify the conditions under which imperfect information results hold. The results refer to the model with government spending and income taxation as fiscal instruments and focus on changes in the steady-state debt to output ratio ψ , and in the Calvo pricing parameter γ . Figure 3.7 and Figure 3.8 report the responses of optimal feedback coefficients and of welfare losses under perfect information and under imperfect information. As regards the optimal feedback coefficients, the analysis limit to assess the changes of the following, as they assume the primary policy role in this framework: feedback of interest rate on cost-push shock θ_η^i ; feedback of government spending on potential output shock $\theta_{y^n}^g$; feedback of tax rate on debt θ_b^τ .

Figure 3.7: Optimal policy and welfare losses (PI and II) for alternative calibrations under discretion



For optimal discretion, Figure 3.7 shows that for higher ψ the debt stabilization bias imposes a stronger reaction of tax rates and constrains monetary policy as θ_η^i gets smaller. This strong debt stabilization bias is better shown in the model without income taxation (see Figure 3.9 in Appendix 3.A): for higher steady-state values of debt monetary policy becomes passive (θ_η^i negative) corroborating the results of Stehn and Vines (2008). As the degree of price rigidity rises (higher γ), it flattens the Phillips curve and raise the relative weight of inflation stabilization in social welfare. Under imperfect information, with income taxation available as an instrument the misperception of shocks generates less inflation after a cost-push shock, which explains that the difference in welfare loss across γ values is higher under PI than under II.

Figure 3.8: Optimal policy and welfare losses (PI and II) for alternative calibrations under commitment

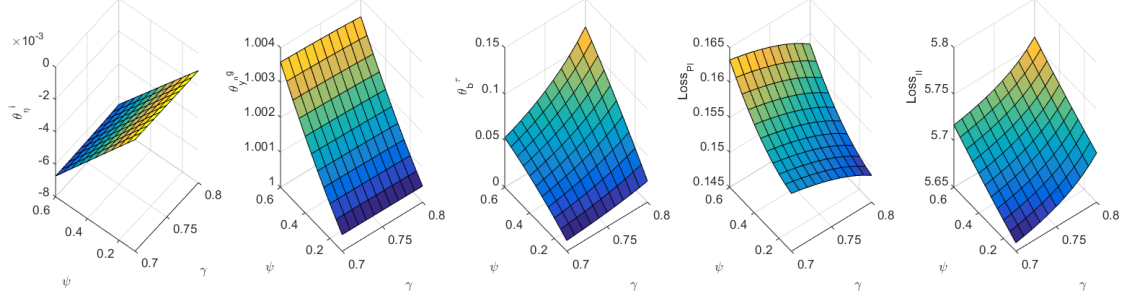


Figure 3.8 plots robustness tests for the optimal commitment case. It shows that for the range of ψ and γ , the availability of income taxation as an instrument offsets the role of monetary policy in a cost-push shock. A stronger debt stabilization role of taxation appears for higher steady-state debt and higher price rigidity. When the degree of price rigidity rises the welfare losses increase under imperfect information, although it decrease under perfect information. This is tied to the finding in the beginning of section 4 that the use of distortionary taxation as a fiscal instrument reduces the value of commitment under imperfect information. With higher price rigidity ($\gamma = 0.8$) the optimal feedback coefficient of tax rate to cost-push shock is smaller and to potential output is higher ($\theta_\eta^\tau = -2.81$; $\theta_{y^n}^\tau = -0.042$), but the optimal reaction of the monetary policy instrument is not improved. Since higher inflation persistence calls tax rate to be more active in debt stabilization (higher θ_b^τ), the economic stabilization effects of information lead to higher welfare loss due to the inappropriate use of policy instruments under imperfect output gap information. When one contrast the welfare implications with the model with only government spending as a fiscal instrument under commitment (Figure 3.10, Appendix 3.A) it is clear that the effect of rising welfare costs for higher price rigidity under imperfect information comes from income taxation.

3.5 Conclusion

Uncertain output gap is assuming a great importance for fiscal policy and for fiscal-monetary interactions as countries target cyclically-adjusted variables to conduct policy. This paper has characterized the optimal fiscal and monetary policy when policymakers face imperfect information about output gap. The results confirm the importance of considering imperfect information, as the use of policy instruments under output gap misperception leads to higher stabilization costs of the economy. The optimal use of policy instruments implies significant welfare losses both under

optimal commitment and discretion. Still, there is a clear value of commitment when compared with the solution under discretion confirming several literature results.

In the joint fiscal-monetary optimization framework the underuse of distortionary income taxation as a policy instrument due to imperfect output gap information amplifies the welfare cost of economic stabilization policy, in particular for commitment. When information is complete, it is optimal to use the tax rate to deal with a cost-push shock as they act in the same margin (Kirsanova and Wren-Lewis, 2012). Output gap misperception, under commitment, drives the policymaker to underuse this instrument facing a cost-push shock and to overreact to a potential output shock – in the later case the main fiscal reaction should be left to government spending. The same misperception problem turns monetary policy active after a cost-push shock when income taxes are available – the monetary policymaker reacts to the probability that is facing a negative potential output shock, which helps explaining the higher welfare costs of imperfect information under commitment, given that a rise in interest rate has a negative effect on private consumption, a component of the utility derived social welfare.

Another effect of the use of fiscal policies when output gap information is imperfect can be observed in the debt dynamics under commitment. It is well established in the optimal fiscal policy literature (Benigno and Woodford, 2004, Schmitt-Grohé and Uribe, 2004 and Leith and Wren-Lewis, 2013) that under optimal commitment policy debt follows a random walk – the policymaker prefers to make smaller but permanent changes in fiscal instruments to service a new level of debt rather than large changes on a temporary basis to return debt to its initial level, because it implies higher welfare costs. When imperfect output gap information is considered, debt still follows a random walk but the new steady state level is significantly different than under perfect information – the amplitude of changes in fiscal instruments due to the reaction to misperceived shocks in the economy leads debt to a different steady-state with higher welfare costs.

It is also shown that when the degree of price rigidity rises the welfare losses increase under imperfect information, although they should decrease if information was perfect.⁷ This is tied to the previous finding that the use of distortionary taxation as a fiscal instrument amplifies the policy effects of imperfect information, leading to higher economic stabilization costs in particular under commitment. With higher price rigidity the optimal feedback coefficient of tax rate to cost-push shock is smaller and to potential output is higher and the optimal reaction of the monetary

⁷see Benigno and Woodford (2004) and Schmitt-Grohé and Uribe (2004) for the implications of price rigidity on optimal fiscal policy under perfect information.

policy instrument is not improved. Since higher inflation persistence calls tax rate to be more active in debt stabilization, the economic stabilization effects of information lead to higher welfare loss.

For further research this framework can be used to evaluate the impact of the use of cyclically-adjusted fiscal targets for macroeconomic stabilization under imperfect output gap information and, with the appropriate changes in the framework of this paper, it is intended to assess the gains of using simple fiscal rules when policymakers cannot observe the state of the economy.

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Appendix

3.A Robustness tests: model without income taxation

Figure 3.9: Optimal discretionary policy and welfare loss for alternative calibrations: i_t and g_t as instruments

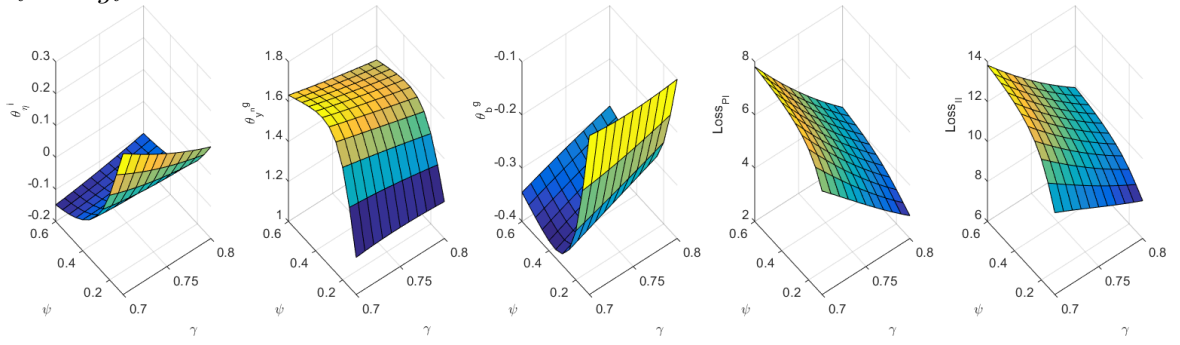
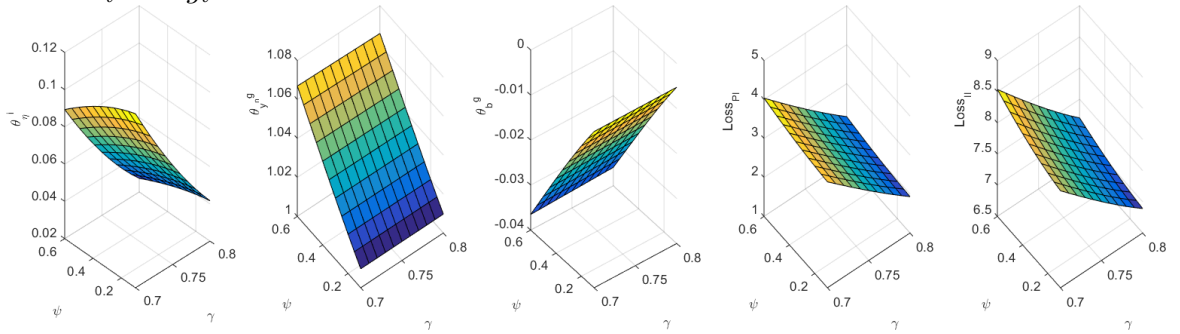


Figure 3.10: Optimal commitment policy and welfare loss for alternative calibrations: i_t and g_t as instruments



3.B The microfounded model

Households

The economy is populated by a continuum of infinitely-lived individuals, who seek to maximize the following objective function,

$$E_t \left\{ \sum_{s=0}^{\infty} \beta^s (u(C_{t+s}) + w(G_{t+s}) - v[N_{t+s}(j)]) \right\}, \quad (3.7)$$

where C_t , G_t , and N_t denote, respectively, private consumption, public consumption and labor supply. Private and public consumption goods aggregates are defined as a Dixit and Stiglitz (1977) consumption indexes

$$C_t = \left[\int_0^1 C_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}}, \quad G_t = \left[\int_0^1 G_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}}$$

respectively, with an elasticity of substitution between goods of different varieties given by $\epsilon > 1$, where $j \in [0, 1]$ denotes the type of good. Optimization of expenditure across individual goods implies the household's demand function for good j , $C_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\epsilon} C_t$ with an associated price level of $P_t = \left[\int_0^1 P_t(j)^{1-\epsilon} dj \right]^{\frac{1}{1-\epsilon}}$.

Households choose C_t and N_t to maximize (3.7) subject to the demand system, the sequence of budget constraints

$$\int_0^1 P_t(j) C_t(j) dj + E_t \{Q_{t+1} D_{t+1}\} \leq D_t + (1 - \tau_t) (W_t(j) N_t(j) + \Pi_t) - T, \quad (3.8)$$

and subject to the transversality condition

$$\lim_{t \rightarrow \infty} E_t \{Q_t D_t\} = 0,$$

where $\int_0^1 P_t(j) C_t(j) dj$ is nominal consumption, D_t are nominal financial assets, Π_t is profit, and W_t is the nominal wage. Tax rate on income is denoted as τ_t and T is a time-invariant lump-sum tax/subsidy. Q_{t+1} is the stochastic discount factor which determines the price in period t of assets with nominal payoffs in $t+1$. The riskless nominal interest rate i_t is represented as

$$E_t \{Q_{t+1}\} = \frac{1}{(1 + i_t)}.$$

We assume that the period utility function takes the functional form

$$U_t = \frac{C_t^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}} + \chi \frac{G_t^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}} - \frac{N_t^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}}.$$

The household's optimality conditions are given by:

$$\frac{W_t}{P_t} = \frac{N_t^{\frac{1}{\varphi}} C_t^{\frac{1}{\sigma}}}{1-\tau_t}, \quad (3.9)$$

$$C_t = E_t \left[\left(\frac{1}{\beta} \frac{P_{t+1}}{P_t} Q_{t+1} \right)^{\sigma} C_{t+1} \right]. \quad (3.10)$$

Log-linearizing equations (3.9) and (3.10) around the steady-state⁸ we get

$$w_t - p_t = \frac{1}{\varphi} n_t + \frac{1}{\sigma} c_t + \frac{\bar{\tau}}{1-\bar{\tau}} \hat{\tau}_t,$$

$$c_t = E_t \{c_{t+1}\} - \sigma \left(\hat{i}_t - E_t \{ \pi_{t+1} \} \right), \quad (3.11)$$

where inflation π_t is given by $\left(\frac{P_t}{P_{t-1}} \right) - 1$ and its steady-state value is assumed to be zero.

Firms

A continuum of firms indexed by $j \in [0, 1]$ produce a differentiated good using a linear production function,

$$Y_t(j) = A_t N_t(j), \quad (3.12)$$

and face the demand curve

$$Y_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\epsilon} Y_t, \quad (3.13)$$

where $Y_t = \left[\int_0^1 Y_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}}$ and $a_t = \log(A_t)$ is productivity technology.

The objective function of the firm is given by

$$\sum_{k=0}^{\infty} \gamma^k Q_{t,t} \left[P(j)_t Y(j)_t - W_t \frac{Y(j)_t (1-\varsigma)}{A_t} \right].$$

Price setting follows the usual Calvo (1983) mechanism with $(1-\gamma)$ of firms changing price in a given period, and ς is a time-invariant employment subsidy that

⁸For any variable X_t with steady-state value X , we use the notation $x_t = \log\left(\frac{X_t}{X}\right)$. For any rate r_t we use $\hat{r}_t = r_t - \bar{r}$.

can be used to eliminate the steady-state distortion associated with monopolistic competition and distortionary income taxes. Profit maximization implies that firms that are able to change price in period t will choose:

$$P_t^* = \frac{\sum_{k=0}^{\infty} \gamma^k Q_{t,t} \left[\epsilon W_t P_t^\epsilon \frac{Y_t}{A_t} \right]}{\sum_{k=0}^{\infty} \gamma^k Q_{t,t} [(\epsilon - 1) P_t^\epsilon Y_t (1 - \varsigma)]}.$$

Following Woodford (2003a), the pricing behavior implies the following log-linearized New Keynesian Phillips curve

$$\pi_t = \beta E_t \{ \pi_{t+1} \} + \frac{(1 - \gamma\beta)(1 - \gamma)\varphi}{\gamma(\varphi + \epsilon)} mc_t. \quad (3.14)$$

The real log-linearized marginal costs of production, mc_t , are given by

$$\begin{aligned} mc_t &= w_t - p_t - a_t + \eta_t \\ &= \frac{1}{\varphi} n_t + \frac{1}{\sigma} c_t + \frac{\bar{\tau}}{1 - \bar{\tau}} \hat{\tau}_t - a_t + \eta_t \end{aligned} \quad (3.15)$$

where η_t is a mark-up shock and $\bar{\tau}$ is the steady-state income tax rate.

Government budget constraint

The government buys goods G_t , taxes income with tax rate τ_t , raises lump-sum taxes T , pays an employment subsidy ς and issues nominal debt B_t . The evolution of the nominal debt stock can be written as

$$B_{t+1} = (1 + i_t) B_t + P_t G_t - \tau_t P_t Y_t - T + \varsigma.$$

The stock of debt defines the net value of the households' portfolio at time t , such that $D_t = (1 + i_t) B_t$ (see equation 3.8), where B_t is the stock of government debt at the end of period t and i_t is the nominal interest rate. Following Gali and Monacelli (2008), Kirsanova and Wren-Lewis (2012) and Leith and Wren-Lewis (2013), among others, a subsidy ς is set in steady-state in order to deal with the solvency problems in the efficient equilibrium that arise from the distortions caused by distortionary taxation and imperfect competition in price setting. The steady-state subsidy is financed by lump-sum taxation and both cannot be altered from this steady-state level, ensuring that the steady-state is efficient. The implication is that any changes in the government's budget constraint have to be financed by changes in distortionary taxation, government spending, or debt service costs.

Defining real debt as $b_{t+1} = \frac{B_{t+1}}{P_t}$ and denoting the steady-state ratio of debt to output as $\psi = B/Y$, the government's flow budget constraint can be log-linearized around this steady-state, which yields:

$$\hat{b}_{t+1} = \hat{i}_t + \frac{1}{\beta} \left[\hat{b}_t - \pi_t + \frac{\theta}{\psi} g_t - \frac{\bar{\tau}}{\psi} (\hat{\tau}_t + y_t) \right].$$

where $\theta = \frac{G}{Y}$ denotes the steady-state government spending share. In steady-state, the income tax rate is given by $\bar{\tau} = (1 - \beta) \psi + \theta$.

Equilibrium dynamics

Goods market clearing requires

$$Y_t = C_t + G_t, \quad (3.16)$$

which log-linearized implies

$$y_t = (1 - \theta) c_t + \theta g_t. \quad (3.17)$$

Using (3.17) and the log-linearized production function $y_t = a_t + n_t$, the expression for the firms real marginal costs (3.15) can be rewritten as

$$mc_t = \left[\frac{1}{\varphi} + \frac{1}{\sigma(1 - \theta)} \right] y_t - \frac{\theta}{\sigma(1 - \theta)} g_t + \frac{\bar{\tau}}{1 - \bar{\tau}} \hat{\tau}_t - \left(\frac{1}{\varphi} + 1 \right) a_t + \eta_t \quad (3.18)$$

Efficient allocation

In order to derive a welfare function for policy analysis first the social planner's problem is considered. The social planner ignores nominal inertia and distortionary taxation in deriving optimal allocations. Accordingly, the solution to the social planner's problem provides a benchmark for optimal policy, and can be used to compute the steady-state subsidy which would ensure the steady-state is efficient. The social planner is not constrained by the price mechanism and simply maximizes the representative household's utility (3.7) subject to the technology (3.12) and resource constraint (3.16). Denoting efficient levels by the superscript *, this yields the following optimality conditions for the social planner's problem:

$$\begin{aligned} (C_t^*)^{-\frac{1}{\sigma}} &= \chi (G_t^*)^{-\frac{1}{\sigma}} \\ 0 &= (C_t^*)^{-\frac{1}{\sigma}} - (Y_t^*)^{\frac{1}{\varphi}} A_t^{-(1+\frac{1}{\varphi})} \end{aligned}$$

The efficient level of output is given by $Y_t^* = A_t^{\frac{\sigma(1+\varphi)}{\sigma+\varphi}} (1 + \chi^\sigma)^{\frac{\varphi}{\sigma+\varphi}}$ which, together with the FOC log-linearizes as

$$y_t^* = \left[\frac{(1 + \varphi) \sigma}{\varphi + \sigma} \right] a_t = c_t^* = g_t^*.$$

Decentralization of the efficient allocation under flexible prices

Following Woodford (2003a) the natural rate equilibrium is defined as the flexible price equilibrium without cost-push shocks. Under flexible prices and in the steady-state, the real wage is always equal to the monopolistic mark-up. Variables in natural levels are denoted with superscript n . A steady-state subsidy ς , financed with lump-sum taxes, is employed to optimally offset the distortions due to taxation and monopolistic competition. Optimization implies

$$\left(1 - \frac{1}{\epsilon}\right) = \frac{(1 - \varsigma)}{(1 - \tau_t)} \frac{(N_t^n)^{1/\varphi} (C_t^n)^{1/\sigma}}{A_t}, \quad (3.19)$$

In order to the equilibrium allocation under flexible prices to correspond to the socially optimal allocation the steady-state subsidy must be given by $(1 - \varsigma) = (1 - \frac{1}{\epsilon})(1 - \bar{\tau})$, and government spending must be set according to the rule,

$$\frac{G_t^n}{Y_t^n} = (1 + \chi^{-\sigma})^{-1},$$

that is a constant spending share, or, after log-linearization, $g_t^n = y_t^n$. If both conditions are satisfied (3.19) reduces to

$$(C_t^n)^{-1/\sigma} = \frac{(N_t^n)^{1/\varphi}}{A_t},$$

and the flexible price equilibrium will yield

$$Y_t^n = A_t^{\frac{\sigma(1+\varphi)}{\sigma+\varphi}} \left(1 - \frac{1}{1 + \chi^{-\sigma}}\right)^{-\frac{\varphi}{\sigma+\varphi}},$$

which in log-linear terms is

$$y_t^n = \left[\frac{(1 + \varphi) \sigma}{\varphi + \sigma} \right] a_t = y_t^*.$$

New Keynesian Phillips curve

Under flexible prices, the linearization of (3.19) yields

$$\left[\frac{1}{\varphi} + \frac{1}{\sigma(1-\theta)} \right] y_t^n - \frac{\theta}{\sigma(1-\theta)} g_t^n - \left(\frac{1}{\varphi} + 1 \right) a_t = 0.$$

Combining this expression with (3.18) and (3.14) we get the aggregate supply equation, represented by an expectational Phillips curve of the form

$$\pi_t = \beta E_t \{ \pi_{t+1} \} + k_y (y_t - y_t^n) - k_g (g_t - g_t^n) + k \left(\frac{\bar{\tau}}{1 - \bar{\tau}} \hat{\tau}_t + \eta_t \right),$$

where the elasticities of inflation with regard to output gap, government spending gap and income tax rate are

$$k = \frac{(1 - \gamma\beta)(1 - \gamma)\varphi}{\gamma(\varphi + \epsilon)}; k_y = \frac{k}{\varphi} \left[1 + \frac{\varphi}{\sigma(1 - \theta)} \right]; k_g = \frac{k\theta}{\sigma(1 - \theta)}.$$

3.C Derivation of the social welfare function

The individual utility (3.1) in period t is

$$\frac{C_t^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}} + \chi \frac{G_t^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}} - \frac{N_t^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}} .$$

Following Woodford (2003a) we do a second-order Taylor expansion of the utility function. The general result of a second-order approximation of a variable Z_t is given by:

$$\frac{Z_t - Z}{Z} \approx z_t + \frac{1}{2} z_t^2 + O[2] ,$$

where $z_t = \log(Z_t/Z)$ and $O[2]$ represents terms that are of order higher than 2 in the bound on the amplitude of the relevant shocks. A second-order expansion of the first term yields:

$$\begin{aligned} u(C_t) &= u_C C_t + \frac{1}{2} u_{CC} C_t^2 + O[2] \\ &= u_C C \left(g_t + \frac{1 + \frac{u_{CC}}{u_C} C}{2} c_t^2 \right) + O[2] \\ &= u_C C \left(c_t + \frac{1 - \sigma^{-1}}{2} c_t^2 \right) + O[2] , \end{aligned} \tag{3.20}$$

where $\frac{1}{\sigma} \equiv -\frac{u_{CC}}{u_C} C = -\frac{w_{GG}}{w_G} G$.

Similarly, for the second term of the utility we have,

$$\begin{aligned} w(G_t) &= w_G G_t + \frac{1}{2} w_{GG} G_t^2 + O[2] \\ &= w_G G \left(g_t + \frac{1 + \frac{w_{GG}}{w_G} G}{2} g_t^2 \right) + O[2] \\ &= w_G G \left(g_t + \frac{1 - \sigma^{-1}}{2} g_t^2 \right) + O[2] . \end{aligned} \tag{3.21}$$

The final term in utility can be approximated as follows. Given the production function (3.12) labor supply can be written as

$$\begin{aligned}
N_t &= \int_0^1 \frac{Y_t(j)}{A} dj \\
N_t &= \frac{Y_t}{A} \int_0^1 \left(\frac{P_t(j)}{P_t} \right)^{-\epsilon} dj \\
n_t &= y_t + \log \left[\int_0^1 \left(\frac{P_t(j)}{P_t} \right)^{-\epsilon} dj \right]
\end{aligned}$$

and, as it is shown in Woodford (2003a),

$$n_t = y_t + \frac{\epsilon}{2} \text{var}_j \{p_t(j)\} + O[2]$$

$$\begin{aligned}
v(N_t) = v(Y_t/A_t) &= v_N N n_t + \frac{1}{2} v_{NN} N^2 n_t^2 + O[2] \\
&= v_N N \left(n_t + \frac{1 + \frac{v_{NN}}{v_N} N}{2} n_t^2 \right) + O[2] \\
&= v_N N \left(y_t + \frac{\epsilon}{2} \text{var}_j \{p_t(j)\} + \frac{1 + \varphi^{-1}}{2} y_t^2 \right) + tip + O[2],
\end{aligned}$$

where $\frac{1}{\varphi} \equiv \frac{v_{NN}}{v_N} N$ and *tip* represents “terms independent of policy.”

Using these expressions, individual utility can be written as

$$\begin{aligned}
U_t - U &\simeq u_C C \left(c_t + \frac{1 - \sigma^{-1}}{2} c_t^2 \right) + w_G G \left(g_t + \frac{1 - \sigma^{-1}}{2} g_t^2 \right) \\
&\quad - v_N N \left(y_t + \frac{\epsilon}{2} \text{var}_j \{p(j)\} + \frac{1 + \varphi^{-1}}{2} y_t^2 \right) + tip + O[2]. \quad (3.22)
\end{aligned}$$

To remove the linear terms of the above expression we follow Kirsanova and Wren-Lewis (2012) and Beetsma and Jensen (2004). First, given that $\theta = G/Y$, we can simplify the expression as follows

$$\begin{aligned}
\frac{U_t - U}{u_C Y} &= (1 - \theta) \left(c_t + \frac{1 - \sigma^{-1}}{2} c_t^2 \right) + \frac{w_G}{u_C} \theta \left(g_t + \frac{1 - \sigma^{-1}}{2} g_t^2 \right) \\
&\quad - \frac{v_N N}{u_C Y} \left(y_t + \frac{\epsilon}{2} \text{var}_j \{p_t(j)\} + \frac{1 + \varphi^{-1}}{2} y_t^2 \right) + tip + O[2]. \quad (3.23)
\end{aligned}$$

If the government removes distortions from monopolistic competition and distortionary taxation in steady-state using a subsidy $(1 - \bar{\varsigma}) = (1 - \frac{1}{\epsilon})(1 - \bar{\tau})$, the efficient steady-state can be attained and

$$(\bar{C}^*)^{-\frac{1}{\sigma}} = \chi (\bar{G}^*)^{-\frac{1}{\sigma}} \Rightarrow \frac{w_G}{u_C} = 1,$$

and also

$$(\bar{C}^*)^{-\frac{1}{\sigma}} = \frac{(\bar{N}^*)^{\frac{1}{\varphi}}}{A} \Leftrightarrow \frac{(\bar{N}^*)^{\frac{1}{\varphi}}}{(\bar{C}^*)^{-\frac{1}{\sigma}}} = A \Rightarrow \frac{v_N}{u_C} \frac{N}{Y} = 1,$$

so that we can remove the linear terms of the welfare function

$$\begin{aligned} \frac{U_t - U}{u_C Y} &= (1 - \theta) \left(c_t + \frac{1 - \sigma^{-1}}{2} c_t^2 \right) + \theta \left(g_t + \frac{1 - \sigma^{-1}}{2} g_t^2 \right) \\ &\quad - \left(y_t + \frac{\epsilon}{2} \text{var}_j \{p_t(j)\} + \frac{1 + \varphi^{-1}}{2} y_t^2 \right) + tip + O[2], \end{aligned}$$

and rewrite (3.23) as

$$\mathbf{W}_t = -\frac{1}{2} \left\{ \epsilon \text{var}_j \{p_t(j)\} + \frac{1}{\varphi} (y_t - y_t^n)^2 - \frac{1 - \theta}{\sigma} (c_t - c_t^n)^2 - \frac{\theta}{\sigma} (g_t - g_t^n)^2 \right\}$$

Using the following lemma, proofed in Woodford (2003a),

$$\sum_{t=0}^{\infty} \beta^t \text{var}_j \{p_t(j)\} = \sum_{t=0}^{\infty} \beta^t \frac{\gamma}{(1 - \beta\gamma)(1 - \gamma)} \pi_t^2,$$

and using the conventional notation for gap variables we get the final formula for the social welfare losses:

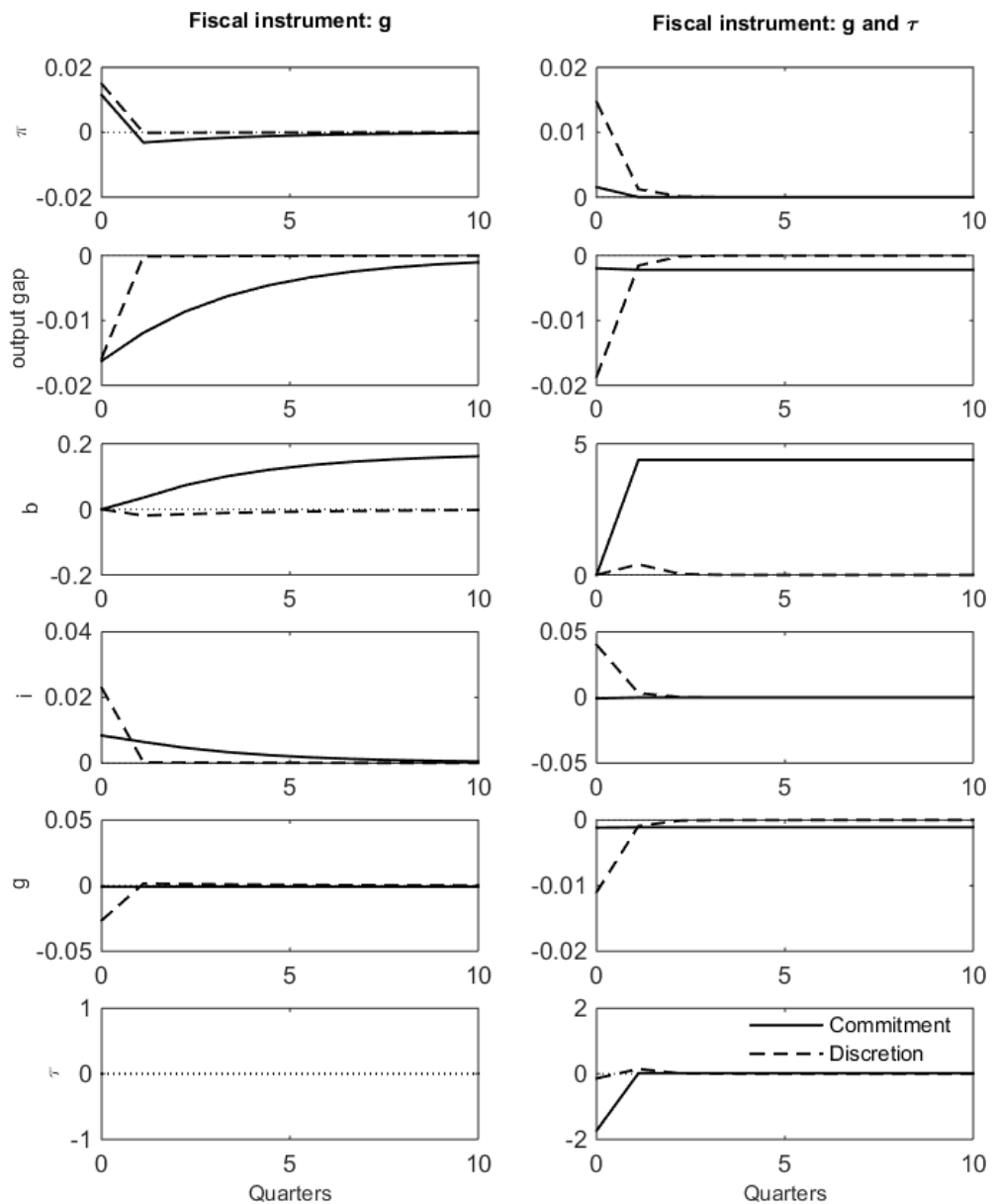
$$\mathbf{W}_t = -\frac{1}{2} E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \lambda_{\pi} \pi_t^2 + \lambda_y (y_t - y_t^n)^2 + \lambda_c (c_t - c_t^n)^2 + \lambda_g (g_t - g_t^n)^2 \right\},$$

where $\lambda_{\pi} = \frac{\varphi\epsilon}{(\varphi+\epsilon)\kappa}$, $\lambda_y = \frac{1}{\varphi}$, $\lambda_c = \frac{1-\theta}{\sigma}$, and $\lambda_g = \frac{\theta}{\sigma}$.

3.D Optimal policy with perfect information

Under perfect information (PI), Figure 3.11 and Figure 3.12 show the impulse response functions (IRF) of key variables under commitment and discretion following, respectively, a one standard error (1SE) positive cost-push shock and a 1SE negative potential output shock.

Figure 3.11: IRF to a 1SE positive cost-push shock under perfect information: commitment and discretion



Start by characterizing optimal commitment policy, when only government spending is available as an instrument, monetary policy responds to the increase in

inflation generated by the cost-push shock, raising interest rates in both the initial and subsequent periods. This rise in real interest rates induces a fall in consumption, and hence in the output gap, which reduces real marginal cost and therefore inflation. Higher interest rates raise the level of debt, which increases gradually but, eventually, stabilizing at a new higher level – debt under optimal commitment policy follows a random walk, as in joint monetary-fiscal optimization benchmarks of Benigno and Woodford (2004) and Schmitt-Grohé and Uribe (2004) which can be seen as an extension of Barro (1979) tax smoothing literature. Permanently higher debt leads to permanently higher interest payments, which requires a permanently lower level of government spending to ensure solvency. Lower government spending is costly, however, as the welfare function is convex and there is discounting. Hence, under commitment, the policymaker prefers to lower government spending by a smaller amount while permanently keeps a new higher level of debt, rather than change it by a larger amount on a temporary basis to return debt to its initial level. Table 3.1 shows a small but negative fiscal feedback coefficient of government spending on debt (when g_t is the only fiscal instrument). When income taxes are available as a fiscal instrument there is an initial attempt to directly offset the cost-push shock by cutting tax rate, as explained by Kirsanova and Wren-Lewis (2012) and in the previous section: lower income taxes increase the incentive to work, which directly reduces the inflationary consequences of the cost-push shock, so they are more efficient at reducing inflation than higher interest rates because they act on the same margin as the distortionary cost-push shock. This cut in taxes would on its own substantially increase debt so it is offset by a one-off cut in interest rates.

Under optimal discretionary policy, the inability of the monetary authority to control inflation tightly via expectations results in the classic inflation stabilization bias (Currie and Levine, 1993 and Woodford, 2003b). Because he is unable to commit to high interest rates in the future, the policymaker raises interest rates strongly in the first period, which induces a large recession but then interest rates quickly return to zero. The hike in interest rate raises the level of debt but, under optimal discretionary policy, the policymaker cannot commit to higher debt in future periods, so the only time-consistent solution is the one in which there is no incentive, at any stage, to reduce debt through unexpected changes in government spending or interest rates – debt stabilization bias (Leith and Wren-Lewis, 2013). It now becomes optimal for fiscal policy to play an active role in the reduction of government debt and to assist the central bank in the control of inflation by cutting government spending strongly. Table 3.1 shows that the coefficients associated with debt under discretion are considerable higher than under commitment. When income taxation

is available as fiscal instrument, it is used by the policymaker to partially offset the cost-push shock together with a hike in interest rates. The cut in taxes and rise in interest rates lead to a higher debt so government spending is temporarily cut. In order to ensure that debt returns to the original steady-state, the policymaker needs to rise taxes in the following periods. Under discretion the debt stabilization bias dominates the policy as in Stehn and Vines (2008).

Figure 3.12: IRF to a 1SE negative potential output shock under perfect information: commitment and discretion

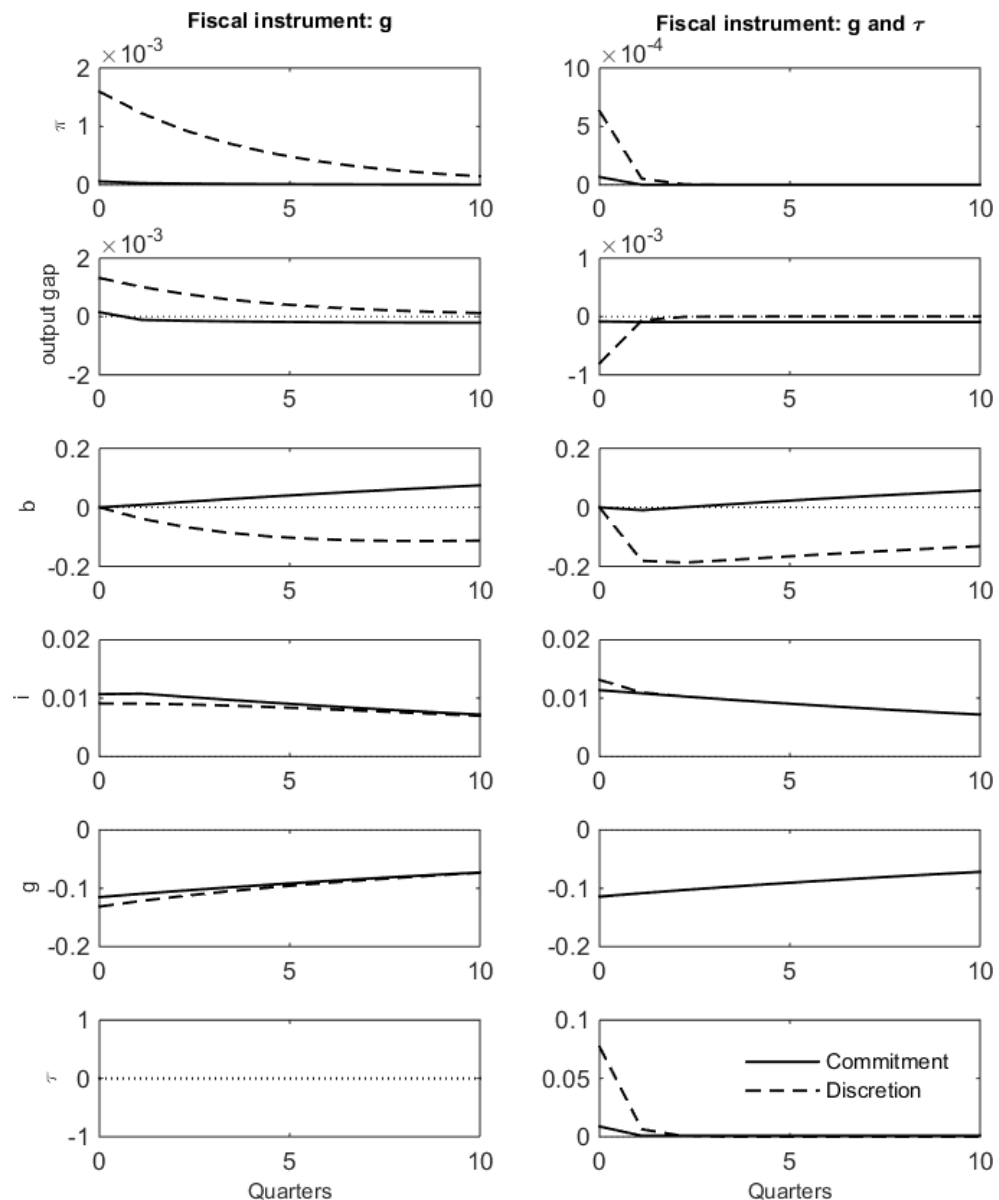


Figure 3.12 details the paths of key endogenous variables following a negative potential output shock. Via Phillips curve, a negative potential output shock gen-

erates inflation, to which, in the case of optimal commitment policy and when only government spending is available as a fiscal instrument, monetary policy responds through rising interest rates which induces a fall in consumption and leads to a higher debt. In a similar mechanism as described for a positive cost-push shock, a permanent fall in government spending and in output is sufficient to support the new higher steady-state debt without generating inflation. When income taxation is available the policymaker initially rises taxes which fuels inflation, so interest rate is slightly higher in the initial period. From Table 3.1 one can observe that under commitment the optimal feedback of interest rate and government spending to potential output is almost unchanged when income taxation is introduced and the more efficient instrument to deal with this shock is government spending.

The optimal discretionary solution entails a more substantial difference, since it requires greater short-term movement in policy instruments. A negative potential output shock generates inflation and the monetary policymaker rises interest rates to contain it. Due to the debt stabilization bias referred above, under discretion the fiscal policymaker assumes an active role in containing debt, so interest rate rises less than in commitment, government spending drops more and negative output gap is larger. This, in turn, generates more inflation in the initial period. When income taxation is available the fiscal authorities are forced to raise taxes by more than they would under commitment, which fuels inflation, but also serves to reduce debt initially. Given the rise in tax rate and the drop in debt, interest rate is initially higher when income taxation is available, amplifying the negative effects in consumption and output, hence amplifying negative output gap.