Estimating a DSGE with Limited Asset Market Participation for the Euro Area*

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Abstract

We propose an estimated medium scale closed economy DSGE model. We characterize the business cycle properties of the model with limited asset market participation (LAMP). Our study is focused on the analysis of the size of the proportion of LAMP households in the Euro area. We find that it is difficult to have an exact measure of this proportion, because its estimate depends crucially on the model specification. Secondly, we assume a time varying fraction of LAMP and we estimate its evolution over time. In contrast with popular wisdom, we find that LAMP has been increasing steadily starting from 1992. Moreover, its contribution to consumption growth volatily is substantial.

1 Introduction

The 2007 financial crisis has stimulated the search for new developments in Dynamic Stochastic General Equilibrium (DSGE) models that typically assumed complete financial markets and relied on the representative agent assumption. One widespread feature in the new wave of DSGE models is the distinction between patient (savers) and impatient (borrowers) households (Curdía and Woodford, 2010; Gelain, 2010; Gerali, Neri, Sessa and Signoretti, 2010; Gertler and Kiyotaki, 2010, Gertler and Karadi, 2011; Villa , 2013). This characterization allows to model financial and banking shocks, but the interest rate policy remains a powerful tool in shaping the intertemporal choices of both borrowers and savers. Furthermore, it has been observed that financial frictions dampen the effects of the productivity shocks typically considered in the DSGE literature, and the financial accelerator effects seem to be of limited importance (Christensen and Dib, 2007, Christiano et al. 2010).

In these models the interest rate policy of the central bank remains a powerful tool, capable of affecting the intertemporal choices of all households. This assumption seems at odds with empirical

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wealth distribution and the microeconomic evidence of household behavior. In fact according to Iacoviello and Pavan (2013) 40% of US households hold no wealth and no debt and similar figures are observed in the Euro area (Cowell, Karagiannaki and McKnight, 2012). Anderson, Inoue and Rossi (2013) use US microdata to estimate individual-level impulse responses as well as multipliers for government spending and tax policy shocks. They find that wealthiest individuals behave according to the predictions of standard DSGE models, but the poorest individuals tend to neglect interest rate changes and adopt consumption patterns that closely follow their current disposable income dynamics. For this reason they suggest that DSGE models should incorporate the Limited Asset Market Participation hypothesis (LAMP henceforth), where a fraction of Non-Ricardian households do not hold any wealth and entirely consume their disposable income in each period.

The implications of the LAMP hypothesis has been investigated in a number of theoretical studies (Galí et al., 2004; Bilbiie, 2008; Motta and Tirelli, 2012, 2013a, 2013b). Other theoretical studies have investigated the potential role played by LAMP in allowing DSGE models to replicate certain business cycle facts, notably the consumption response to public expenditure shocks (Galí et al. 2007; Colciago, 2011) and to investment shocks (Furlanetto et al. 2013), and the reaction of output, hours and consumption to productivity shocks (Furlanetto and Seneca, 2012).

The LAMP hypothesis has been incorporated in empirical DSGE models of the euro area. Coenen and Straub (2005), Ratto, Roeger and Veld (2008), Forni, Monteforte and Sessa (2009) and Coenen, Straub and Trabandt (2012) estimates values of the fraction of Non-Ricardian households for the Euro area economy comprised between 18% and 37%. All these papers pay particular attention to the effects of exogenous fiscal shocks (government spending and transfers shocks) on consumption. These shocks are found to have a significant positive impact on consumption when LAMP is taken into account, although their effects depend on the size of the proportion of Non-Ricardian agents.

We propose a medium scale closed economy DSGE model akin to Smets and Wouters (2003, 2007) model with a simple dimension of heterogeneity, the degree of asset market participation. The justification for reconsidering the relative importance of LAMP in an empirical DSGE model of the Euro area is based on three considerations. The first one is that previous contributions impose restrictions on wage setters behavior such that Non Ricardian households behavior (and preferences) cannot affect wage-setting decisions. This is a potentially serious shortcoming because the theoretical literature on LAMP has shown that Non Ricardian households impact on wage setting decisions plays a crucial role on the dynamic stability of the model. Thus, since Bayesian estimation techniques constrain estimated parameters to be consistent with model determinacy, these restrictions might bias estimates of the proportion of Non Ricardian households. Moreover, the estimated reaction of the economy to shocks is likely to change substantially if one allows for wage Phillips curves that take into account of LAMP effects on wage-setting decisions. The second reason is that previous contributions typically rely on a households' preference specification that includes external habits in differences. From theoretical contributions of the LAMP hypothesis (Motta and Tirelli 2012, 2013a,b) it is well known that under external habits the marginal utility of consumption of Non Ricardian households is very high when different wealth holdings generate large consumption differentials between the two households groups. This, in turn, would play a key role in inducing indeterminacy. We therefore build on Menna and Tirelli (2014) who consider habits in *ratios* in place of *differences* and non separability between consumption and labor effort. As the authors show, this enables to enlarge the area of determinacy, thus allowing for a possibly larger value of the fraction of LAMP. Finally, the third justification for our empirical analysis is that the relative importance of LAMP restriction might well change over time. For instance, Bilbiie and Straub (2012, 2013) forcefully argue that structural changes in the degree of asset market participation explain variations in the monetary policy transmission mechanism in the US. For this reason we shall devote particular effort to investigate how the proportion of Non-Ricardian households has changed over certain sample periods. In addition changes in LAMP might be due to cyclical variations in credit market conditions. It has now become standard practice in empirical DSGE models to incorporate exogenous "risk premium" shocks that capture a deterioration in credit market conditions and generate a fall in aggregate demand trough their effect in the Euler consumption equation. Following Albonico and Rossi (2013), we consider a complementary option, allowing for the possibility that the share of Non-Ricardian households is subject to a shock.

Our results in a nutshell. The baseline version of the model is compared with the separable-habits-in-differences preferences specification. We obtain a 29% estimate of the fraction of LAMP in the baseline model versus a 14% share in the separable utility specification, thus implying a great dependence of these estimates on the specific structure of the model used. This sounds a word of caution on the possibility of extracting estimates of the degree of LAMP from empirical DSGE models. The underlying intuition for this claim is easily spelled out. Habits in differences imply greater volatility of the economy for any given share of Non-Ricardian households. Thus, a smaller estimate for this parameter is sufficient to match empirical moments of the observed variables. The opposite holds true for the habits-in-ratio non separable utility specification adopted in the baseline model. To support our intuition we show that LAMP has crucial consequences for business cycle movements in response to shock, but the parameter estimates obtained under the two alternative preference specifications allow to obtain estimated IRFs that are almost coincident.

We then assume that the fraction is time varying and we model it as an exogenous shock. We obtain that this shock is important in explaining consumption volatility, as it can account for 33% of consumption growth volatility. It is instead less relevant for output growth and inflation volatility. This result is not irrelevant and the importance of this kind of shock to explain consumption growth is confirmed by the historical decomposition, which stresses the fact that the LAMP shock has been an important source of variation in consumption in the Euro area during the periods of crisis of the sample considered, in particular during the sovereign debt crisis. Note that this result is confirmed even if we simultaneously estimate the standard "risk premium" shock. Finally, we find that the fraction of LAMP has been quite volatile over the sample and increased steadily starting from 1992.

The paper is organized as follows. Section 2 introduces the model and section 3 presents the Bayesian estimation results of the baseline model. Section 4 investigate the time dimension of LAMP and section 5 concludes.

2 The model

2.1 Households

There is a continuum of households indexed by $i \in [0, 1]$. A possibly time-varying share $1 - \theta_t$ of households (Ricardian households) can access financial markets, buy and sell government bonds, accumulate physical capital and rent capital services to firms. The remaining θ_t households (Non-Ricardian or LAMP households) do not have access to financial markets and consume all their disposable labor income. When we allow for time variations in the fraction of LAMP, we assume that θ_t is an exogenous shock following an AR(1) process. Wage setting decisions are taken by labor-type specific unions indexed by $j \in [0,1]$. Households supply as many labor services to satisfy labor demand.

2.1.1 Ricardian households

Ricardian households are indexed by $o \in [0, 1-\theta_t]$. Their lifetime utility function is similar to Smets and Wouters (2007) and is the following:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{1}{1-\sigma} \left(\frac{c_t^o}{c_{t-1}^b} \right)^{1-\sigma} \exp\left(\frac{(\sigma-1)\,\varepsilon_t^l}{1+\phi_l} \left(h_t^o\right)^{1+\phi_l} \right) \right\} \tag{1}$$

where we define $c_t^o = \frac{C_t^o}{z_t}$ and $c_t = \frac{C_t}{z_t}$. C_t^o is Ricardian consumption, while C_t is aggregate consumption. As we will show below, z_t is a labour-augmenting permanent technology shock. h_t^o are hours worked by Ricardians and ε_t^l a labor supply shock with AR(1) process:

$$\hat{\varepsilon}_t^l = \rho_l \hat{\varepsilon}_{t-1}^l + \eta_t^l$$

where η_t^l is an i.i.d. Normal innovation term and ρ_l is the shock persistence.

Parameter $0 < \beta < 1$ is the discount factor, $\sigma > 0$ denotes relative risk aversion and ϕ_l is the inverse of labor supply elasticity. Parameter $0 < b < 1$ measures the degree of external habit formation in consumption. Thus, households' preferences depend positively on the ratio of the current, individually chosen level of consumption (adjusted for growth), c_t^o, and the aggregate consumption level that was chosen in the previous period. Differently to Smets and Wouters (2007), we introduce habits in ratio to allow for a wider area of determinacy of the model. As shown in Motta and Tirelli (2012, 2013a, 2013b) in fact the combination of consumption habits and LAMP may cause indeterminacy for a plausible share of LAMP households. Menna and Tirelli (2014?) show that habits in ratio can overcome this problem.

The Ricardian household budget constraint is the following:

$$\begin{aligned}
\left(1+\tau_t^c\right) P_t C_t^o + P_t I_t^o + \frac{B_{t+1}^o}{\varepsilon_t^b} \;=\;& R_{t-1} B_t^o + \left(1-\tau_t^l-\tau_t^{wh}\right) W_t^o h_t^o + P_t D_t^o \\
&+ \left(1-\tau_t^k\right)\left[R_t^k u_t^o - a\left(u_t^o\right) P_t\right] K_t^o + \tau_t^k \delta P_t K_t^o + TR_t^o - T_t^o
\end{aligned} \tag{2}$$

Ricardian households allocate their resources between consumption C_t^o, investments I_t^o and the public bonds B_{t+1}^o, issued by the government. They receive income from labor services h_t^o paid at the nominal wage W_t^o, dividends from firms' profits D_t^o, from renting capital services $u_t^o K_t^o$ at the rate R_t^k and from holding government bonds. Here P_t is the level of prices and R_t is the nominal interest rate, K_t^o is the physical capital stock and u_t^o is the intensity of utilizing capital stock.

The fiscal authority imposes different kinds of taxes to the households. In particular, Ricardian households pay taxes on consumption purchases at a tax rate τ_t^c, on wage income at a rate τ_t^l and on capital income at a rate τ_t^k. They are also burdened with an additional payroll tax τ_t^{wh}, representing the households's contribution to social security, and with lump sum taxes T_t^o. They receive a transfer TR_t^o.

The household owns physical capital stock which evolves according to the following capital accumulation equation:

$$K_{t+1}^{o} = (1-\delta) K_t^o + \varepsilon_t^i \left[1 - S\left(\frac{I_t^o}{I_{t-1}^o} \right) \right] I_t^o \tag{3}$$

where δ is the depreciation rate and the term $S\left(\frac{I_t^o}{I_{t-1}^o}\right)$ represents adjustment costs on investments as in Christiano, Eichenbaum and Evans (2005). The adjustment costs function is assumed to take the following form, in line with CCW:

$$S\left(\frac{I_t^o}{I_{t-1}^o} \right) = \frac{\gamma_I}{2} \left(\frac{I_t^o}{I_{t-1}^o} - g_z \right)^2 \tag{4}$$

where $\gamma_I > 0$ and g_z is the economy's trend growth rate.

The intensity of utilizing physical capital is subject to a proportional cost, which is assumed to take the following specification (see Christiano, Eichenbaum and Evans (2005)):

$$a\left(u_t^o\right) = \gamma_{u1}\left(u_t^o - 1\right) + \frac{\gamma_{u2}}{2}\left(u_t^o - 1\right)^2 \tag{5}$$

The problem of Ricardian households consists of maximizing their utility 1 with respect to C_t^o, B_{t+1}, I_t^o, K_{t+1}^o, u_t^o, subject to their budget constraint 2 and the capital accumulation equation 3, taking into account the functional forms 4 and 5.

We obtain the following first order conditions:

$$\frac{\left(c_t^o\right)^{-\sigma} c_{t-1}^{b(\sigma-1)} \exp\left(\frac{(\sigma-1)\varepsilon_t^l}{1+\phi_l} \left(h_t^o\right)^{1+\phi_l} \right) \frac{1}{z_t}}{\left(1+\tau_t^c\right)} = \Lambda_t^o \tag{6}$$

$$R_t = \pi_{t+1} \frac{\Lambda_t^o}{\beta \varepsilon_t^b \Lambda_{t+1}^o} \tag{7}$$

$$\begin{aligned} 1 \;=\; & Q_t^o \varepsilon_t^i \left\{ 1 - \gamma_I \left(\frac{I_t^o}{I_{t-1}^o} - g_z \right) \frac{I_t^o}{I_{t-1}^o} - \frac{\gamma_I}{2} \left(\frac{I_t^o}{I_{t-1}^o} - g_z \right)^2 \right\} \\ & + \frac{\Lambda_{t+1}^o}{\Lambda_t^o} Q_{t+1}^o \varepsilon_{t+1}^i \beta \gamma_I \left(\frac{I_{t+1}^o}{I_t^o} - g_z \right) \left(\frac{I_{t+1}^o}{I_t^o} \right)^2 \end{aligned} \tag{8}$$

$$\frac{\Lambda_{t+1}^o}{\Lambda_t^o} \beta \left\{ \left(1-\tau_{t+1}^k\right) \left[\frac{R_{t+1}^k}{P_{t+1}} u_{t+1}^o - a\left(u_{t+1}^o\right) \right] + \tau_{t+1}^k \delta + Q_{t+1}^o (1-\delta) \right\} = Q_t^o \tag{9}$$

$$\frac{R_t^k}{P_t} = \gamma_{u1} + \gamma_{u2}\left(u_t^o - 1\right) \tag{10}$$

where Λ_t^o / P_t and $\Lambda_t^o Q_t^o$ are the Lagrange multipliers associated respectively with 2 and 3. Λ_t^o represents the shadow price of a unit of consumption good, thus equation 6 shows the marginal utility of consumption out of income. Equation 7 is the Euler equation. Q_t^o measures the shadow price of a unit of investment good and represent then the Tobin's Q. Equations 8 and 9 are the first order conditions for investment and capital respectively. Equation 10 equates the return from capital utilization to its cost.

The latter equation implies that u_t^o is identical across households, so that $u_t^o = u_t$.

2.1.2 Non Ricardian households

Non Ricardian households (LAMP households) are indexed by $rt \in [1-\theta_t, \theta_t]$. They do not own physical capital nor they enjoy income from profits in the form of dividends. Their lifetime utility function is symmetric to Ricardians' utility:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{1}{1-\sigma} \left(\frac{c_t^{rt}}{c_{t-1}^b} \right)^{1-\sigma} \exp\left(\frac{(\sigma-1)\,\varepsilon_t^l}{1+\phi_l} \left(h_t^{rt}\right)^{1+\phi_l} \right) \right\} \tag{11}$$

where, similarly, we define $c_t^{rt} = \frac{C_t^{rt}}{z_t}$.

LAMP agents are forced to consume their disposable labor income in each period according to their budget constraint:

$$\left(1+\tau_t^c\right) P_t C_t^{rt} = \left(1-\tau_t^l-\tau_t^{wh}\right) W_t^{rt} h_t^{rt} + TR_t^{rt} - T_t^{rt} \tag{12}$$

Moreover, they delegate wage decisions to unions, so that there are no first order conditions for them.

2.1.3 Labor market

Wage decisions are made by labor type specific unions j. Each union j sets W_t^j, households supply as many hours to the labor market j, so that

$$h_t^j = \left(\frac{W_t^j}{W_t} \right)^{-\frac{1+\lambda_t^w}{\lambda_t^w}} h_t^d \tag{13}$$

where λ_t^w stands for the possibly time-varying wage net markup and h_t^d is aggregate labor demand.

Agents are distributed uniformly across unions so that aggregate demand for labor type j is split uniformly across the households. The individual hours worked is common across households, so that $h_t^i = h_t = \int_0^1 h_t^j dj$. Combining this expression with 13:

$$h_t = h_t^d \int_0^1 \left(\frac{W_t^j}{W_t} \right)^{-\frac{1+\lambda_t^w}{\lambda_t^w}} dj \tag{14}$$

The common labor income is given by:

$$W_t^i h_t^i = h_t^d \int_0^1 W_t^j \left(\frac{W_t^j}{W_t} \right)^{-\frac{1+\lambda_t^w}{\lambda_t^w}} dj$$

2.1.4 Wage setting

Wages are staggered à la Calvo (1983). Union j receives permission to optimally reset the nominal wage with probability $(1-\xi_w)$. Those unions which cannot reset the wage adjust the wage according to the following scheme:

$$W_t^j = g_{z,t}\pi_{t-1}^{\chi_w}\bar{\pi}_t^{1-\chi_w}W_{t-1}^j$$

where $\pi_t = \frac{P_t}{P_{t-1}}$ and $\bar{\pi}_t$ is the possibly time-varying gross inflation objective, which is exogenous. $\pi = \bar{\pi}$ is steady state inflation.

The problem of the union is to maximize the sum of discounted weighted average of the utility functions of the two households:

$$\max_{\tilde{W}_t^j} E_t \sum_{s=0}^{\infty} (\xi_w \beta)^s \left\{ \begin{array}{c} \frac{1-\theta_{t+s}}{1-\sigma}\left(\frac{c_{t+s}^o}{c_{t+s-1}^b}\right)^{1-\sigma} \exp\left(\frac{(\sigma-1)\varepsilon_{t+s}^l}{1+\phi_l}\left(h_{t+s}^o\right)^{1+\phi_l}\right) \\ +\frac{\theta_{t+s}}{1-\sigma}\left(\frac{c_{t+s}^{rt}}{c_{t+s-1}^b}\right)^{1-\sigma} \exp\left(\frac{(\sigma-1)\varepsilon_{t+s}^l}{1+\phi_l}\left(h_{t+s}^{rt}\right)^{1+\phi_l}\right) \end{array} \right\}$$

subject to the budget constraints of the households, 2 and 12, and 14.

The corresponding FOC is:

$$\begin{aligned} 0 &= E_t \sum_{s=0}^{\infty} (\xi_w\beta)^s c_{t+s-1}^{b(\sigma-1)} \exp\left(\frac{(\sigma-1)\varepsilon_{t+s}^l}{1+\phi_l}(h_{t+s})^{1+\phi_l}\right) h_{t+s}^j \cdot \\ &\cdot \left\{ \begin{array}{c} \tilde{W}_t^j \frac{\left(1-\tau_{t+s}^l-\tau_{t+s}^{wh}\right) g_{z,t,t+s}\pi_{t,t+s-1}^{\chi_w}\bar{\pi}_{t,t+s}^{1-\chi_w}}{\left(1+\tau_{t+s}^c\right)P_{t+s}z_{t+s}} \left(1-\frac{1+\lambda_{t+s}^w}{\lambda_{t+s}^w}\right)\left[(1-\theta_{t+s})\left(c_{t+s}^o\right)^{-\sigma}+\theta_{t+s}\left(c_{t+s}^{rt}\right)^{-\sigma}\right] \\ +\frac{1+\lambda_{t+s}^w}{\lambda_{t+s}^w}\left[(1-\theta_{t+s})\left(c_{t+s}^o\right)^{-\sigma} MRS_{t+s}^o + \theta_{t+s}\left(c_{t+s}^{rt}\right)^{-\sigma} MRS_{t+s}^{rt}\right] \end{array} \right\} \end{aligned}$$

where:

$$\pi_{t,t+s-1} = \begin{cases} 1 & \text{for } s=0 \\ \pi_t \cdot \pi_{t+1} \cdot \ldots \cdot \pi_{t+s-1} & \text{for } s=1,2\ldots. \end{cases}$$

$$\bar{\pi}_{t,t+s} = \begin{cases} 1 & \text{for } s=0 \\ \bar{\pi}_t \cdot \bar{\pi}_{t+1} \cdot \ldots \cdot \bar{\pi}_{t+s} & \text{for } s=1,2\ldots. \end{cases}$$

$$MRS_t^o = -\frac{U_h^o\left(c_t^o, h_t^o\right)}{U_c^o\left(c_t^o, h_t^o\right)} = c_t^o\varepsilon_t^l\left(h_t^o\right)^{\phi_l}$$

$$MRS_t^{rt} = -\frac{U_h^{rt}\left(c_t^{rt}, h_t^{rt}\right)}{U_c^{rt}\left(c_t^{rt}, h_t^{rt}\right)} = c_t^{rt}\varepsilon_t^l\left(h_t^{rt}\right)^{\phi_l}$$

and $g_{z,t,t+s} = \prod_{s=1}^{s} g_{z,t+s}$.

The aggregate wage index W_t is:

$$W_t = \left[\xi_w\left(g_{z,t}\pi_{t-1}^{\chi_w}\bar{\pi}_t^{1-\chi_w}W_{t-1}\right)^{\frac{1}{\lambda_t^w}} + (1-\xi_w)\left(\tilde{W}_t\right)^{\frac{1}{\lambda_t^w}}\right]^{\lambda_t^w}$$

2.2 Firms

2.2.1 Final good firms

The final good Y_t is produced under perfect competition. A continuum of intermediate inputs $Y_t(z)$ is combined as in Kimball (1995). The final good producers maximize profits:

$$\max_{Y_t, Y_t^z} P_t Y_t - \int_0^1 P_t^z Y_t^z dz$$

$$\text{s.t.} \quad \int_0^1 G\left(\frac{Y_t^z}{Y_t}; \lambda_t^p\right) dz = 1$$

with G strictly concave and increasing and $G(1) = 1$ and λ_t^p is the markup, which is assumed to be an exogenous process.

From the first order conditions we obtain:

$$Y_t^z = Y_t G'^{-1}\left[\frac{P_t^z}{P_t} \int_0^1 G'\left(\frac{Y_t^z}{Y_t}\right)\left(\frac{Y_t^z}{Y_t}\right) dz\right]$$

2.2.2 Intermediate good firms

Intermediate firms z are monopolistically competitive and use as inputs capital services, $u_t^z K_t^z$, and labor services, h_t^z. The production technology is:

$$Y_t^z = \varepsilon_t^a [u_t^z K_t^z]^\alpha [z_t h_t^z]^{1-\alpha} - z_t \Phi$$

where Φ are fixed costs of production and z_t represents the labour-augmenting permanent technology shock and evolves according to:

$$\frac{z_t}{z_{t-1}} = g_{z,t} = \left(1 - \rho_{g_z}\right) g_z + \rho_{g_z} g_{z,t-1} + \eta_t^{g_z}$$

Profits maximization leads to the following:

$$\frac{u_t K_t}{h_t} = \frac{\alpha}{(1-\alpha)} \frac{\left(1 + \tau^{wf}\right) W_t}{R_t^k} \tag{15}$$

We obtain that the capital-labour ratio is equal across firms. Then also the marginal cost is equal across firms:

$$MC_t = \alpha^{-\alpha} (1-\alpha)^{-(1-\alpha)} \left(\varepsilon_t^a\right)^{-1} z_t^{-(1-\alpha)} \left(R_t^k\right)^\alpha \left[\left(1 + \tau^{wf}\right) W_t\right]^{1-\alpha} \tag{16}$$

2.2.3 Price setting

Prices are sticky à la Calvo (1983). Firm z receives permission to optimally reset its price with probability $\left(1 - \xi_p\right)$. Those firms which cannot reset the price adjust the price according to the following scheme:

$$P_t^z = \pi_{t-1}^{\chi_p} \bar{\pi}_t^{1-\chi_p} P_{t-1}^z$$

where $\bar{\pi}_t$ is the time-varying gross inflation objective.

The problem of the firm is to choose the optimal price $\tilde{P}_t^z$ which maximizes profits :

$$\max_{\tilde{P}_t^z} E_t \sum_{s=0}^{\infty} \xi_p^s \Xi_{t,t+s} \left[\frac{\tilde{P}_t^z \pi_{t,t+s-1}^{\chi_p} \bar{\pi}_{t,t+s}^{1-\chi_p}}{P_{t+s}} Y_{t+s}^z - \frac{MC_{t+s}^z}{P_{t+s}} Y_{t+s}^z \right]$$

subject to

$$Y_{t+s}^z = G'^{-1} \left(\frac{\tilde{P}_t^z \pi_{t,t+s-1}^{\chi_p} \bar{\pi}_{t,t+s}^{1-\chi_p}}{P_{t+s}} \int_0^1 G' \left(\frac{Y_{t+s}^z}{Y_{t+s}} \right) \frac{Y_{t+s}^z}{Y_{t+s}} dz \right) Y_{t+s}$$

where MC_t^z is the nominal marginal cost and $\Xi_{t,t+s}$ is the stochastic discount factor for real payoffs:

$$\Xi_{t,t+s} = \varepsilon_{t+s}^b \beta^s \frac{\Lambda_{t+s}^o}{\Lambda_t^o}$$

Following Smets and Wouters (2007), we define $\omega_t = \frac{\tilde{P}_t^z}{P_t} \int_0^1 G' \left(\frac{Y_t^z}{Y_t} \right) \frac{Y_t^z}{Y_t} dz$ and $x_t = G'^{-1}(\omega_t)$, so that the first order condition is:

$$E_t \sum_{s=0}^{\infty} \xi_p^s \frac{\Xi_{t,t+s}}{P_{t+s}} Y_{t+s}^z \left[\tilde{P}_t^z \pi_{t,t+s-1}^{\chi_p} \bar{\pi}_{t,t+s}^{1-\chi_p} + \left(\tilde{P}_t^z \pi_{t,t+s-1}^{\chi_p} \bar{\pi}_{t,t+s}^{1-\chi_p} - MC_{t+s}^z \right) \frac{1}{G'^{-1}(\omega_{t+s})} \frac{G'(x_{t+s})}{G''(x_{t+s})} \right] = 0$$

The aggregate price index is:

$$\begin{aligned} P_t &= \left(1-\xi_p\right) \tilde{P}_t^z G'^{-1} \left(\frac{\tilde{P}_t^z \int_0^1 G' \left(\frac{Y_{t+s}^z}{Y_{t+s}} \right) \frac{Y_{t+s}^z}{Y_{t+s}} dz}{P_t} \right) \\ &\quad + \xi_p \pi_{t-1}^{\chi_p} \bar{\pi}_t^{1-\chi_p} P_{t-1} G'^{-1} \left(\frac{\pi_{t-1}^{\chi_p} \bar{\pi}_t^{1-\chi_p} P_{t-1} \int_0^1 G' \left(\frac{Y_{t+s}^z}{Y_{t+s}} \right) \frac{Y_{t+s}^z}{Y_{t+s}} dz}{P_t} \right) \end{aligned}$$

2.3 Fiscal policy

The government budget constraint in nominal terms is:

$$P_t G_t + R_{t-1} B_t + TR_t = B_{t+1} + T_t + \tau_t^c P_t C_t + \left(\tau_t^l + \tau_t^{wh} + \tau_t^{wf} \right) W_t h_t + \tau_t^k \left[R_t^k u_t - \left(a(u_t) + \delta \right) P_t \right] K_t$$

where G_t is public spending.

In the benchmark version of the model, we keep fiscal variables, but government spending, constant.

2.4 Monetary policy

Following CCW, the monetary authority sets the nominal interest rate according to a log-linear Taylor rule:

$$\hat{R}_t = \phi_R \hat{R}_{t-1} + (1-\phi_R)\left(\widehat{\bar{\pi}}_t + \phi_\pi\left(\hat{\pi}_{t-1} - \widehat{\bar{\pi}}_t\right) + \phi_y \hat{y}_t\right) + \phi_{\Delta\pi}\left(\hat{\pi}_t - \hat{\pi}_{t-1}\right) + \phi_{\Delta y}\left(\hat{y}_t - \hat{y}_{t-1}\right) + \hat{\varepsilon}_t^r \quad (17)$$

$\widehat{\bar{\pi}}_t$ is the log-linear deviation of trend (gross) inflation or inflation objective from its steady state $\bar{\pi}$, which evolves according to an AR(1) process.

2.5 Aggregation

The relationship between aggregate and individual variables is:

$$C_t = \theta C_t^{rt} + (1-\theta) C_t^o$$

$$K_t = (1-\theta) K_t^o$$

$$I_t = (1-\theta) I_t^o$$

$$B_t = (1-\theta) B_t^o$$

$$d_t = (1-\theta) d_t^o$$

$$TR_t = \theta TR_t^{rt} + (1-\theta) TR_t^o$$

$$T_t = \theta T_t^{rt} + (1-\theta) T_t^o$$

2.6 Market clearing

The aggregate resource constraint:

$$Y_t = C_t + G_t + I_t + a(u_t) K_t$$

Labor market clearing:

$$\begin{aligned} h_t &= \int_0^1 h_t^j dj \\ &= h_t^d \int_0^1 \left(\frac{W_t^j}{W_t}\right)^{-\frac{1+\lambda_t^w}{\lambda_t^w}} dj \\ &= s_{W,t} h_t^d \end{aligned}$$

where $s_{W,t} = \int_0^1 \left(\frac{W_t^j}{W_t}\right)^{-\frac{1+\lambda_t^w}{\lambda_t^w}} dj$ is wage dispersion across the differentiated labor services.
Capital market:

$$u_t K_t = u_t \int_0^1 K_t^z dz$$

Firms' aggregate demand for labor input:

$$h_t^d = \int_0^1 h_t^z dz$$

Good market:

$$\int_0^1 Y_t^z dz = \int_0^1 \left(\frac{P_t^z}{P_t}\right)^{-\frac{1+\lambda_t^p}{\lambda_t^p}} dz Y_t = s_{P,t} Y_t$$

where $s_{P,t} = \int_0^1 \left(\frac{P_t^z}{P_t}\right)^{-\frac{1+\lambda_t^p}{\lambda_t^p}} dz$ is price dispersion across differentiated goods.
Note that both $s_{W,t}$ and $s_{P,t}$ vanish in the log-linearized version of the model.

3 Bayesian estimation

3.1 Data and methodology

We estimate the log-linearized model with Bayesian techniques using quarterly data from the AWM database (12^{th} update) based on Fagan, Henry and Mestre (2001). The set of observable variables includes output, private consumption and investments and compensation per employee in real terms, inflation, the short term interest rate in nominal terms and total employment. Inflation has been calculated as the log difference in the GDP deflator. Output, consumption, investments and wages are transformed in log differences and total employment has been detrended with a linear trend. In the below estimation, the sample period ranges from 1972:Q2 to 2011:Q4.

We relate the employment variable, e_t, to the unobserved hours-worked variable, h_t, by an auxiliary equation following Christoffel, Coenen and Warne (2008):

$$\hat{e}_t = \frac{\beta}{1+\beta} E_t \hat{e}_{t+1} + \frac{1}{1+\beta} \hat{e}_{t-1} + \frac{(1-\xi_e)(1-\beta\xi_e)}{(1+\beta)\xi_e} \left(\hat{h}_t - \hat{e}_t\right) \tag{18}$$

The parameter ξ_e determines the sensitivity of employment with respect to hours worked.

We estimate the mode of the posterior distribution by maximizing the log posterior function, which combines the prior information on the parameters with the likelihood of the data, using a Monte-Carlo based optimization routine. The Metropolis-Hastings algorithm is then used to get the complete posterior distribution with a sample of 250000 draws (dropping the first 20% draws) and a scale for the jumping distribution of 0.35.

We include different shocks in our estimation procedure. The baseline specification includes the following shocks: temporary TFP shock, investment specific shock, price markup shock, wage markup shock, monetary shock and government spending shock. The risk premium and the LAMP shock are included alternatively, as it will be clear later.

3.2 Calibration and priors

We calibrate some parameters and we estimate the remaining ones.

The discount factor β is fixed at 0.99, in line with a steady-state real interest rate of about 2%. The steady-state depreciation rate δ is set to 0.025, which implies a 10% annual depreciation rate. The capital share α is set at 0.3, in line with the literature. The monetary authority's long-run (net) inflation objective $\bar{\pi} - 1$ is assumed to equal 1.9% at an annualized rate, consistent with the ECB's quantitative definition of price stability of inflation being below, but close to 2% (see CCW). The steady state growth rate is set to 2% in annual terms, in line with CCW. The elasticity of the demand for goods is set at 6, which implies a steady state price markup of 20%. The steady state wage markup is also set at 20%. The ratios of fiscal variables to GDP are borrowed from Coenen, Straub and Trabandt (2012) and are collected in Table 1. In particular, government spending to GDP ratio is fixed at 21.5%, in line with the sample average, and public debt to GDP ratio is set at 60% in annual terms, in line with the Maastricht objective. We set the ratios of taxes and transfers to GDP equal among consumers and also to the aggregate.

The remaining parameters are estimated with Bayesian techniques. Priors are collected in the first panel of Table 2. Most of the priors are set in line with the existing literature on Euro area model estimation (Christoffel, Coenen and Warne (2008), Coenen, Straub and Trabandt (2012) and Smets and Wouters (2003, 2005)). In particular, parameters measuring the persistence of the shocks are set to be Beta distributed, with mean 0.5 and standard deviation 0.1 and the standard errors of the innovations are assumed to follow an Inverse-gamma distribution. The parameters governing price and wage setting, habits, utilization elasticity, interest rate smoothing and the steady state fraction of LAMP are also Beta distributed. In particular, the steady state fraction of LAMP θ is assumed to be Beta distributed with mean 0.3 and standard deviation 0.1, in line with Coenen, Straub and Trabandt (2012).

Risk aversion, the inverse of Frisch elasticity and the parameters of the Taylor rule are Normally distributed, while the degree of investment adjustment costs is Gamma distributed.

3.3 Posterior parameters

Table 2 collects the posterior estimates of the structural parameters and coefficients governing shock processes. Notably, we obtain an estimate for the steady state value of the fraction of LAMP which is substantially higher than what has been found in the literature from a model without specific characteristics of fiscal policy. Coenen and Straub (2005) find a fraction of 0.37 only when they introduce the extreme assumption that LAMP households are exempted from paying taxes and include distortionary taxes. Note that in this baseline version of the model the tax structure is symmetric for the two types of agents. Moreover, government spending is an exogenous shocks and all tax variables are kept constant. However, we obtain a value of θ which is higher than what obtained by Coenen, Straub and Trabandt (2012), 0.18, and Coenen and Straub (2005) with lump sum taxation (0.25). Here in fact we obtain a value of 0.29 in the baseline specification with non separable utility and habits in ratios. The estimate drops to 0.14 when we use a separable utility function and habits in differences.

parameter	value
β	0.99
δ	0.025
α	0.3
α_p	6
λ_p	0.2
λ_w	0.2
$\bar{\pi}-1$	0.0047
g_z	0.005
$\frac{b}{y}$	2.4
$\frac{g}{y}$	0.215
$\frac{t}{y}$	0.12
$\frac{tr}{y}$	0.167
τ^c	0.223
τ^l	0.116
τ^k	0.35
$\tau^w h$	0.127
$\tau^w f$	0.232

Table 1: Calibrated parameters

All structural parameters assume economically plausible values, even if some of them show some differences across the different specifications. The most striking case concerns the inverse elasticity of labor supply ϕ_l. Even if very differently, it remains within plausible bounds for both specification, implying a labor supply elasticity of 0.28 and 0.83 respectively. In particular, under the baseline model, parameter ϕ_l is estimated to be bigger, which is associated also to a higher estimate of the fraction of LAMP. This could be due to the fact that higher inverse labor supply parameter values implies a wider area of determinacy, allowing for higher estimates of θ.

The other structural parameters do not differ significantly across the two specifications.

Concerning the persistence of shocks, the main differences arise for the investment specific shock, which is much more persistent under the baseline specification and the monetary shock, which is less persistent under the baseline specification.

The estimated standard errors of shocks are in general in line with the existing literature (see Christoffel, Coenen and Warne (2008) for comparison).

3.4 Impulse response analysis

It has been already shown in several papers that LAMP has important implications for the responses to the different shocks. In particular, LAMP is found to be crucial to replicate the empirical responses to government spending shocks and investment specific shocks.

The effects of a government spending shock when LAMP is introduced have been analyzed by Galí, López-Salido and Vallés (2007), who find that the response of consumption to a positive government spending shock becomes positive with the presence of LAMP, which is in line with empirical findings.

	Prior distribution			Posterior distribution					
				Baseline			Separable utility		
parameters	shape	mean	std dev	post. mean	90% HPD interval		post. mean	90% HPD interval	
σ	norm	1	0.375	1.5942	1.3961	1.8027	1.143	0.9474	1.3303
b	beta	0.7	0.1	0.6016	0.4692	0.7392	0.6854	0.6357	0.7375
ϕ_l	norm	2	0.75	3.629	2.5721	4.7133	1.2007	0.004	2.0355
θ	beta	0.3	0.1	0.2852	0.2295	0.3404	0.1408	0.1095	0.171
γ_I	gamma	4	0.5	5.5768	4.8251	6.225	6.0866	5.3924	6.8578
σ_u	beta	0.5	0.15	0.8583	0.8313	0.8847	0.7949	0.7626	0.8268
χ_p	beta	0.75	0.1	0.1438	0.1073	0.1804	0.1584	0.1073	0.1982
ξ_p	beta	0.75	0.1	0.886	0.8676	0.9	0.8868	0.8735	0.9
χ_w	beta	0.75	0.1	0.8542	0.7585	0.9482	0.7144	0.5692	0.8548
ξ_w	beta	0.75	0.1	0.9299	0.9151	0.9447	0.8953	0.8631	0.9259
ξ_e	beta	0.5	0.15	0.89	0.8744	0.9052	0.8926	0.88	0.9052
ϕ_r	beta	0.9	0.05	0.9021	0.8706	0.9343	0.9044	0.8831	0.9258
ϕ_π	norm	1.7	0.1	1.8899	1.7779	2.0174	1.8973	1.7704	2.0175
$\phi_{\Delta y}$	norm	0.063	0.05	0.2476	0.2057	0.2899	0.1841	0.148	0.2198
$\phi_{\Delta\pi}$	norm	0.3	0.1	0.1372	0.0809	0.1941	0.1921	0.1381	0.2472
Φ	norm	1.45	0.25	1.5084	1.3869	1.6444	1.5105	1.4786	1.5413
$\bar{e}$	norm	0	2	-1.5978	-3.4678	0.3663	-1.8025	-3.5747	-0.021
ρ_a	beta	0.5	0.1	0.9518	0.9504	0.9529	0.951	0.9488	0.9529
ρ_b	beta	0.5	0.1	0.9276	0.9076	0.9529	0.9195	0.8961	0.9431
ρ_i	beta	0.5	0.1	0.6645	0.5628	0.7604	0.4418	0.3248	0.5504
ρ_r	beta	0.5	0.1	0.4132	0.3129	0.5067	0.4863	0.4047	0.5701
ρ_p	beta	0.5	0.1	0.9511	0.9488	0.9529	0.9513	0.9493	0.9529
ρ_w	beta	0.5	0.1	0.8552	0.828	0.8817	0.8784	0.8524	0.9044
ρ_g	beta	0.5	0.1	0.8725	0.8306	0.9125	0.8853	0.8392	0.9344
η^a	invg	0.1	2	1.5439	1.1763	1.8945	1.6977	1.422	1.9653
η^b	invg	0.1	2	0.1761	0.1299	0.2187	0.1077	0.0831	0.1316
η^i	invg	0.1	2	0.3915	0.3183	0.4634	0.4817	0.4116	0.5541
η^r	invg	0.1	2	0.2116	0.1853	0.2384	0.1943	0.171	0.2168
η^p	invg	0.1	2	0.047	0.0374	0.0576	0.0478	0.0391	0.0565
η^w	invg	0.1	2	0.134	0.115	0.1528	0.1163	0.0988	0.133
η^g	invg	0.1	2	0.3187	0.2883	0.349	0.3252	0.2947	0.3561

Table 2: Prior and posterior distributions of estimated parameters

Similarly, Furlanetto, Natvik and Seneca (2013) explain the co-movements of consumption with investment and output, observed in the data, through the presence of LAMP.

Moreover, Furlanetto and Seneca (2012) show how the negative response of hours worked to a positive technology shock, found in the data, is strengthened in a model with LAMP.

In what follows we consider the estimated impulse responses to the main sources of macroeconomic fluctuations, with and without LAMP households.

3.4.1 Impulse responses to a government spending shock

A positive government spending shock has the effect of increasing total demand, thus output. At the same time, the demand stimulus makes inflation go up and thus the monetary authority responds by raising the nominal interest rate. Then, Ricardian consumption drops as a consequence of the so-called crowding out effect. However, when LAMP is taken into account, aggregate consumption decrease is not significant. The upper confidence band is in fact over the steady state. This is due to the presence of LAMP agents, whose consumption is positively affected by the increase of government spending, as they do not experience crowding out effects because they cannot smooth consumption, thus are unaffected by variations of the interest rate, but increase consumption due to the increase of hours worked and wages. This result has already been pointed out by Galí, López-Salido and Vallés (2007).

However, Figure 1 suggests something which can be surprising. Here in fact we are comparing IRFs from the baseline model (black lines) with IRFs from the model without LAMP, i.e. where θ is set to be 0 (red lines). We would have expected that, in line with standard results, when there are no LAMP agents in the economy, the response of aggregate consumption would have been significantly negative. On the contrary, not only this is not significantly negative, but the mean response is also higher than in the baseline model with LAMP. This is probably due to a higher estimate of the risk aversion parameter σ, which is estimated to be higher than 2 in the no-LAMP model, while it is 1.6 in the baseline. In fact, the higher σ, the more the response of aggregate consumption is positive.

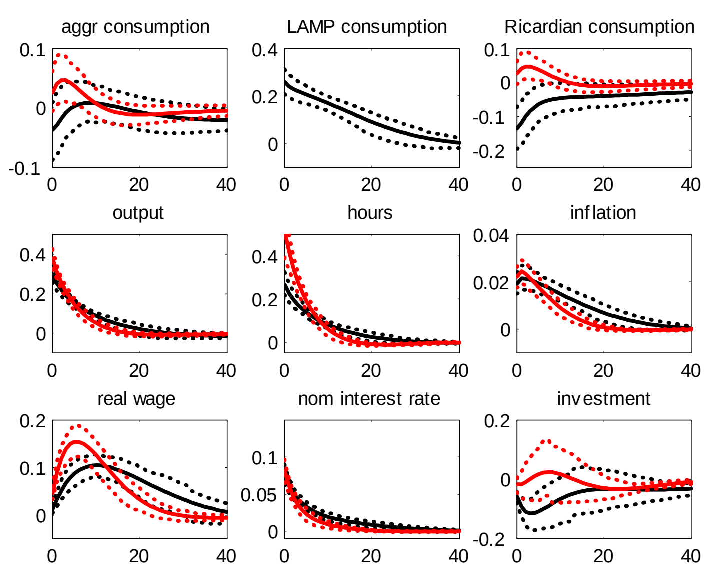

Figure 1. Posterior impulse responses to a government spending shock. Black solid lines: baseline model (mean responses). Red solid lines: no LAMP model (mean responses). Dotted lines: 90% confidence bands.

If we compare instead the baseline model with the separable utility model (Figure 2), we find that in this latter specification the response of aggregate consumption is negative on impact, although it is not significantly negative for all subsequent periods. This is consistent with the presence of a lower fraction of LAMP households and also with the lower estimate of σ.

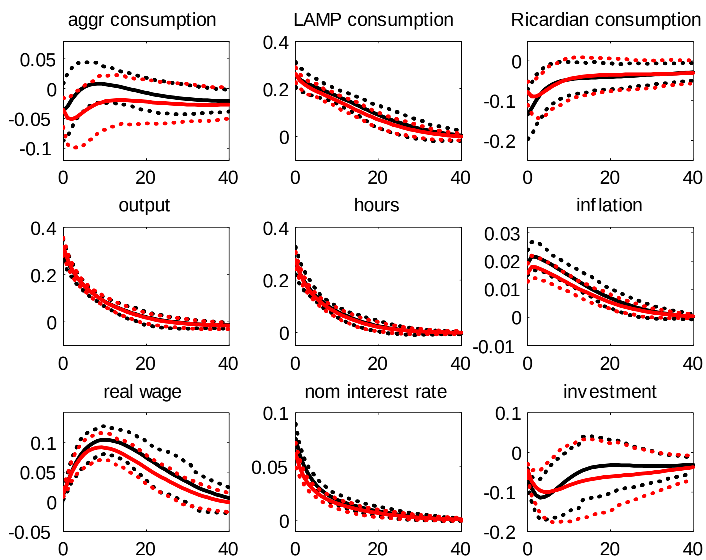

Figure 2. Posterior impulse responses to a government spending shock. Black solid lines: baseline model (mean responses). Red solid lines: separable utility specification (mean responses). Dotted lines: 90% confidence bands.

3.4.2 Impulse responses to an investment specific shock

Furlanetto, Natvik and Seneca (2013) find that when the economy is hit by an investment specific shock, agents who trade in financial markets cut consumption to finance investment. LAMP households instead increase their consumption because the investment specific shock increases hours worked and wages, thus rising labor income. Hence, for a sufficiently high share of LAMP, aggregate consumption may increase.

Figure 3 confirms this result. When LAMP is taken into account the response of consumption is positive (black lines), while it mostly remains negative in the representative agent model (red lines). Moreover, the model with LAMP entails a lower volatility of most macroeconomic variables.

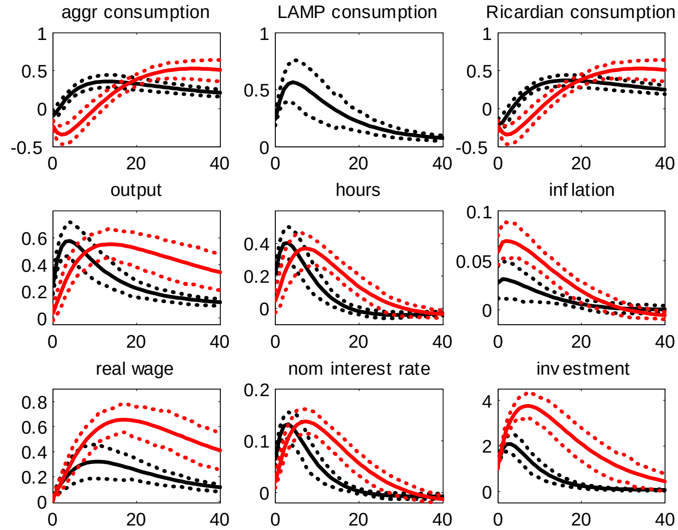

Figure 3. Posterior impulse responses to an investment specific shock. Black solid lines: baseline model (mean responses). Red solid lines: no LAMP model (mean responses). Dotted lines: 90% confidence bands.

In Figure 4, we plot the IRFs comparing the different preference specifications. The two specifications do not imply significant differences in responses. Introducing LAMP is important, but the different specifications are able to match almost the same macroeconomic volatility.

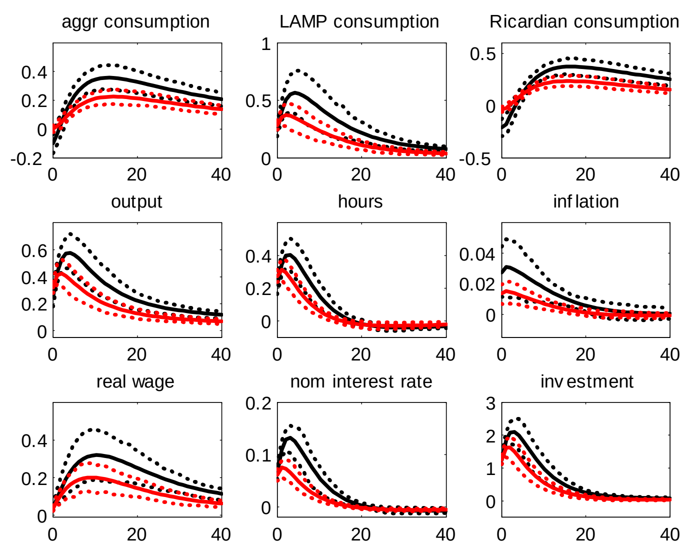

Figure 4. Posterior impulse responses to an investment specific shock. Black solid lines: baseline model (mean responses). Red solid lines: separable utility specification (mean responses). Dotted lines: 90% confidence bands.

3.4.3 Impulse responses to a productivity shock

As shown in many papers (Galí (1999), Francis and Ramey (2005), for example), a positive technology shock in a model which considers nominal and wage rigidities leads to a decline in hours worked. After a positive technology shock in fact, firms can produce a given level of output with a lower amount of hours worked. In addition, given that prices are sticky, output is demand-determined, thus if demand does not increase sufficiently hours will decrease after the shock.

Figure 5 presents the estimated IRFs to a positive technology shock with and without LAMP. The presence of LAMP, as already explained by Furlanetto and Seneca (2012), amplifies the negative effect on hours worked due to real and nominal rigidities. In response to a positive technology shock in fact LAMP agents decrease their consumption, because their labor income decreases, thus curbing aggregate demand and making hours decrease even more. Our estimates might seem be suggesting the opposite, as hours in the baseline case without LAMP (red lines) decline more. But this is due also to other parameters estimates, in particular in this model the technology is found to be three times more volatile than in the model with LAMP, thus implying a lower response of hours. However, we can clearly detect the more contracting effect on aggregate consumption and thus output.

The model is also able to replicate output zero impact response observed in the empirical evidence.[1] As already pointed out by Furlanetto and Seneca (2012), this is driven by the contemporaneous presence of LAMP agents and habits in consumption. Habits in consumption, in fact, limit the expansion in demand, thus delaying the expansionary effect of the shock. In our estimates, we find the degree of habits persistence is higher in the model without LAMP, thus further justifying the zero impact response of output, which remains however over the impact response of output with LAMP.

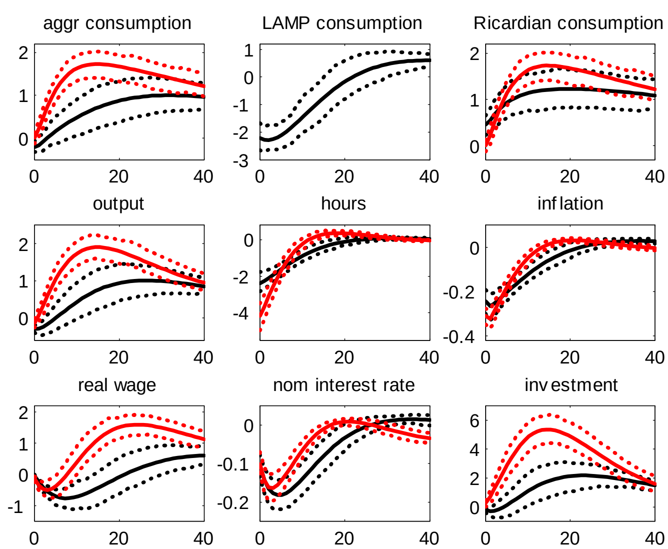

Figure 5. Posterior impulse responses to a technology shock. Black solid lines: baseline model (mean responses). Red solid lines: no LAMP model (mean responses). Dotted lines: 90% confidence bands.

[1]See Basu, Fernald and Kimball (2006) and Francis and Ramey (2005).

Again, also in response to such a shock, considering different types of preferences, does not entail significantly different IRFs, even if the fraction of LAMP is estimated to be different. The models are able to match the same volatility by estimating different values for the structural parameters.

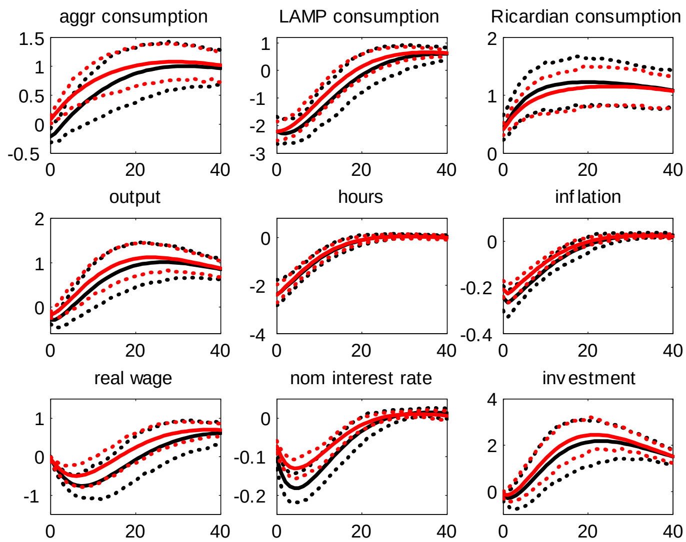

Figure 6. Posterior impulse responses to a technology shock. Black solid lines: baseline model (mean responses). Red solid lines: separable utility specification (mean responses). Dotted lines: 90% confidence bands.

3.4.4 Impulse responses to a risk premium shock

The risk premium shock introduces a gap between the interest rate controlled by the monetary authority and the return on assets held by the households. A positive risk premium shock increases the desired return on assets and reduces current consumption. At the same time, it also increases the cost of capital and reduces the value of capital and investment. This shock has often been used to simulate the recent financial crisis, as it leads to a contemporaneous drop in consumption, investment and output.

Figure 4 compares the IRFs obtained by the estimation of the baseline model with LAMP (black lines) and without LAMP (red lines). We find that the presence of LAMP involves greater losses in terms of aggregate consumption and output. In particular, it takes more time for the system to go back to the steady state.

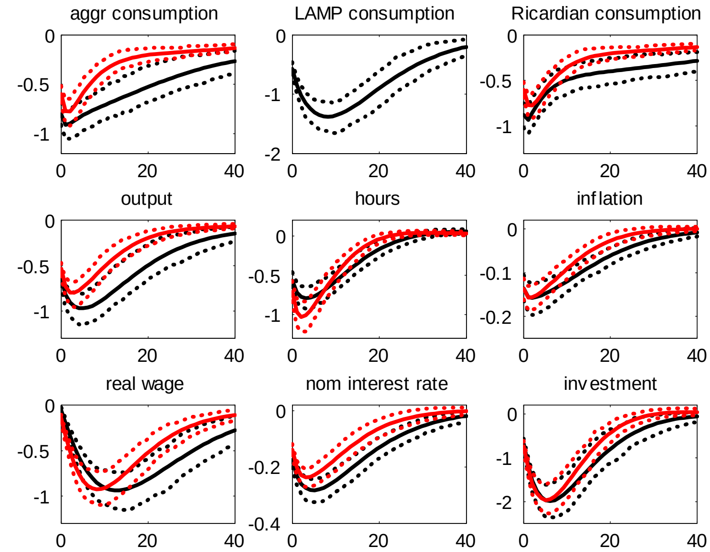

Figure 4. Posterior impulse responses to a risk premium shock. Black solid lines: baseline model (mean responses). Red solid lines: no LAMP model (mean responses). Dotted lines: 90% confidence bands.

Figure 5 shows that the IRFs obtained by the separable utility model (red lines) are very similar to the baseline model IRFs.

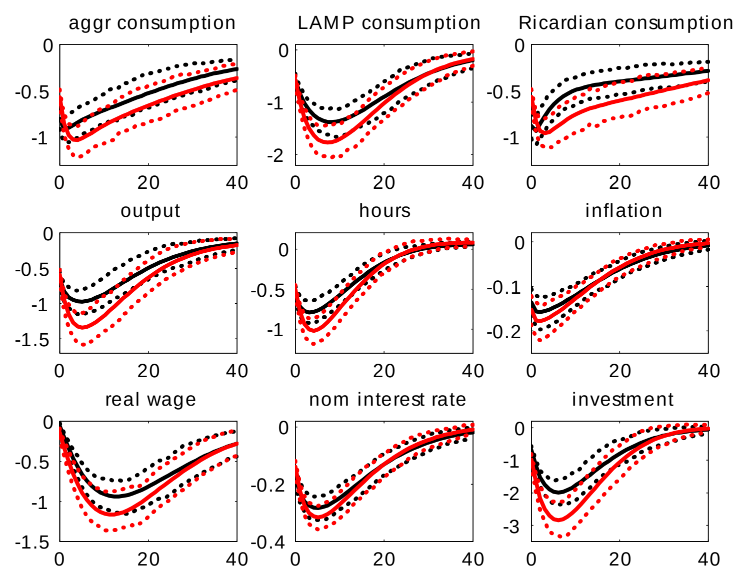

Figure 5. Posterior impulse responses to a risk premium shock. Black solid lines: baseline model (mean responses). Red solid lines: separable utility specification (mean responses). Dotted lines: 90% confidence bands.

4 The fraction of LAMP: time perspective

In this section, we investigate how the fraction of Non Ricardian agents has evolved over time, concentrating on different aspects.

First, we introduce the shock to the LAMP fraction in the model and estimate it as a latent variable, keeping the steady state fraction of LAMP fixed at 0.2852, the value it assumed under the baseline estimates.[2] This exercise enables us to show different interesting results.

4.1 Variance and historical decomposition

In this section we investigate whether and how the LAMP shock is an important feature to take into account.

We find in fact that it accounts for 33% of the variance of consumption growth, which is quite consistent per se (it explains roughly one third of overall volatility) and also if compared to the other contributions: the monetary shock accounts for 27% and the wage mark up shock for 15%, while all other shocks accounts for less. The LAMP shock appears then to be very important in explaining consumption growth volatility, this is a source of variation policymakers should then pay attention to and probably they have not yet considered sufficiently.

It is less important for output growth volatility, even if it explains more than the government spending shock, the investment specific shock and the mark up shocks.

Considering the risk premium shock and the LAMP shock as alternative, the LAMP shock explains roughly the same percentage of the volatility of output and inflation if compared to the risk premium shock (around 15% and 8% respectively), but it is much more important for consumption (the risk premium explains 17% of consumption growth volatility).

If we consider the two shocks together[3] however, we obtain that the risk premium shock still accounts for 19% of consumption growth volatility, while the LAMP shock still explains 12%, more than technology, investment, wage markup and government shocks.

The presence of LAMP also affects variance decomposition in general. In fact, comparing the first and the last panel of Table 3, it appears that when LAMP are taken into account, the technology shock explains less volatility of all variables considered. At the same time, the monetary and wage markup shocks become less important to explain consumption volatility, with the price markup shock explaining much more than without LAMP. The price markup shock seems to be more important also for output and inflation volatility when LAMP is considered.

To support the idea that the LAMP shock is an important source of fluctuation affecting in particular consumption growth, in Figure 1 we plot the historical decomposition of consumption growth. It is evident from the graph that the LAMP shock weights significantly on consumption growth peaks and troughs. In particular, we notice that it explains much during downturns. The CEPR has identified five periods of recession in the Euro Area for the sample considered: 1974:Q3-1975:Q1 (first oil shock), 1980:Q1-1982:Q3 (second oil shock), 1992:Q1-1993:Q3 (EMS crisis), 2008:Q1-2009:Q2 (financial crisis) and 2011:Q3-? (debt crisis). Of course, this dating is based on economic activity instead of consumption, but the periods of contraction in economic activity coincide also with periods of negative consumption growth.

[2] Estimating both the steady state fraction of LAMP and its evolution over time seems to be not the right approach, similarly to estimating the steady state markup and the markup shock together.

[3] Again we estimate the model, keeping the steady state fraction θ fixed at 0.2852.

shock	Baseline			LAMP shock			Risk and LAMP shocks			Baseline no LAMP		
	Δc	Δy	$\Delta\pi$	Δc	Δy	$\Delta\pi$	Δc	Δy	$\Delta\pi$	Δc	Δy	$\Delta\pi$
η^a	7.53	14.54	29.13	12.75	21.86	29.91	7.84	9.98	18.36	15.99	19.33	35.32
η^b	17.00	14.89	8.48	-	-	-	18.74	15.32	0.53	18.63	13.84	16.71
η^i	0.75	2.79	0.24	2.78	5.63	10.03	8.88	5.17	2.64	4.13	1.38	3.77
η^r	33.77	31.77	12.16	27.76	26.41	31.01	24.76	35.01	20.72	39.36	30.26	16.28
η^p	32.45	26.12	29.70	8.02	11.97	13.47	16.68	14.39	19.73	6.91	17.93	16.35
η^w	8.41	5.82	20.12	15.26	12.65	7.44	10.92	7.95	30.51	14.88	9.62	11.23
η^θ	-	-	-	33.23	15.05	7.56	12.10	5.96	7.23	-	-	-
η^g	0.09	4.07	0.17	0.20	6.42	0.57	0.07	6.21	0.29	0.10	7.63	0.34

Table 3: Posterior mean variance decomposition

During the troughs characterizing the oil shocks and the EMS crisis, the negative weight of the LAMP shock on consumption growth is evident. Surprisingly it seems not to have weighted much during the recent financial crisis, while it explains much of the trough of 2011:Q2, during the debt crisis. As it has been already pointed out, the first part of the Great Recession (financial crisis) do not affected the Euro Area activities so much, because the European banking system was quite solid. Instead, the crisis hit the Euro Area through different channels. There were other factors which probably dampened more consumption, in particular monetary shocks during 2008 and wage markup shocks starting from the end of 2008 and during 2009.

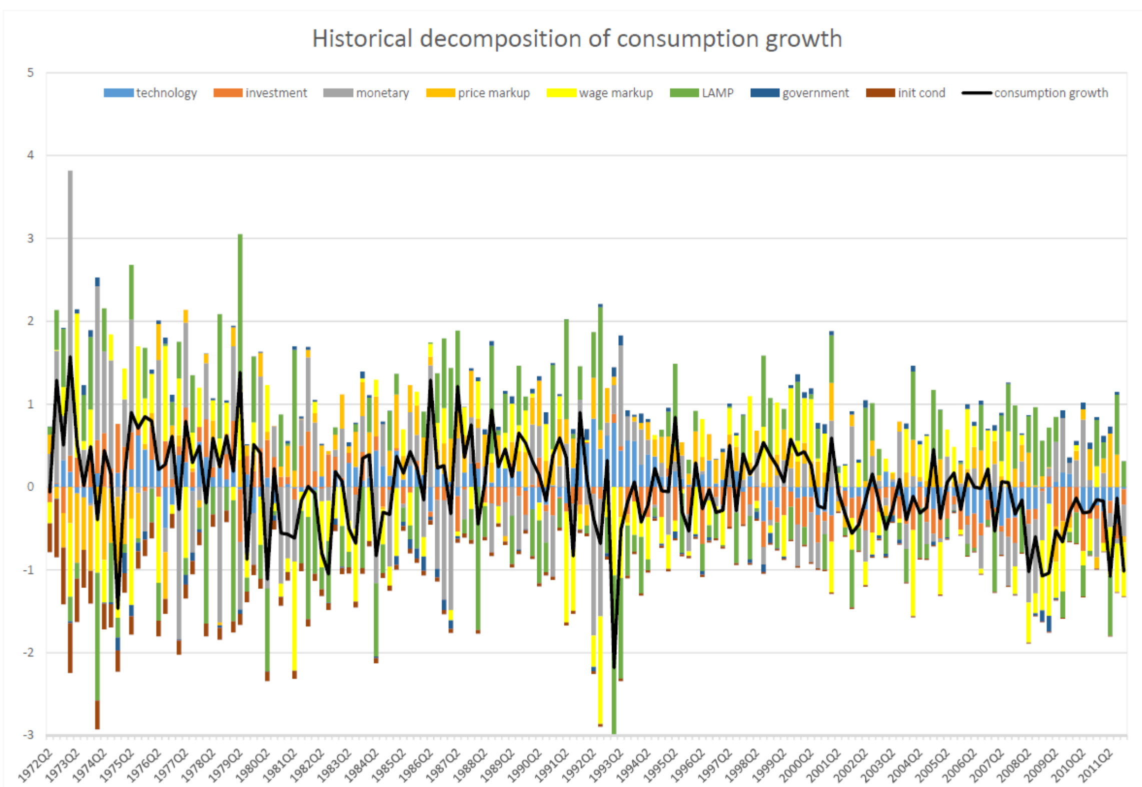

Figure 1. Historical decomposition of consumption growth.

4.2 LAMP time profile

Bayesian estimation techniques enable us to derive an estimate of the fraction of LAMP in the Euro Area. The Bayesian estimation uses the Kalman filter to obtain a state-space representation of the dynamic system and, through a recursive procedure, to derive the log-likelihood, conditional on the set of observables. The same recursive algorithm enables to sequentially update a linear projection for the system and as a by-product to generate smoothed estimates for the endogenous variables.

Figure 2 shows the time profile for the implied fraction of LAMP in the sample considered. The smoothed estimate obtained through the Kalman filter has been centered on the previously estimated steady state value of θ_t (0.2852).

The proportion of LAMP in the economy is estimated to be quite volatile over the sample. It is interesting to note that it has started increasing steadily from 1992:Q4, thus during the EMS crisis. For the next decade it has fluctuated between 0.28 and 0.34 and reached its peak of 0.35 in 2011:Q2.

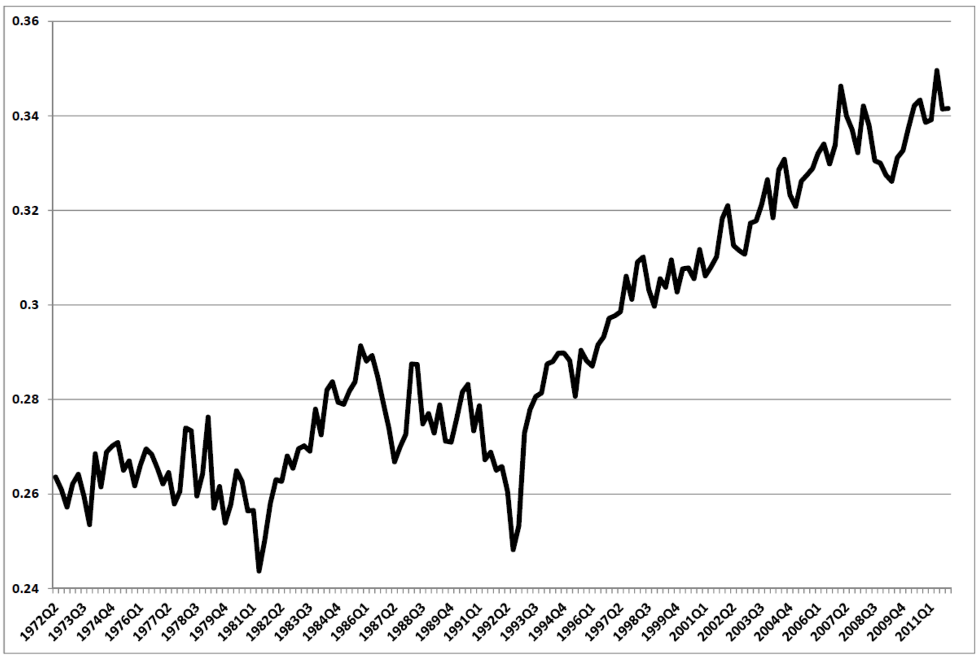

Figure 2. Proportion of LAMP in the Euro Area 1972:Q2-2011:Q4.

4.3 Impulse responses to a LAMP shock

In this section, we analyze the impulse responses to a shock to the fraction of LAMP. Albonico and Rossi (2014) introduce this shock in a DSGE-NK model to analyze the optimal responses of monetary and fiscal policy to a possible crisis scenario. An increase in the fraction of LAMP can be interpreted as an abrupt decrease in credit supply, which prevent a higher fraction of agents to participate in the financial markets, thus becoming (temporarily) LAMP consumers. This shock has the expected effect of reducing the real interest rate on impact. At the same time, it decreases LAMP consumption by an abruptly decreasing labor income (both wages and hours go down). This leads to a recession, as aggregate consumption decrease and thus demand and output. Given the lower demand, also inflation goes down and so does the nominal interest rate. Ricardian consumption still increases because of the decrease in the real interest rate, which supports also investments.

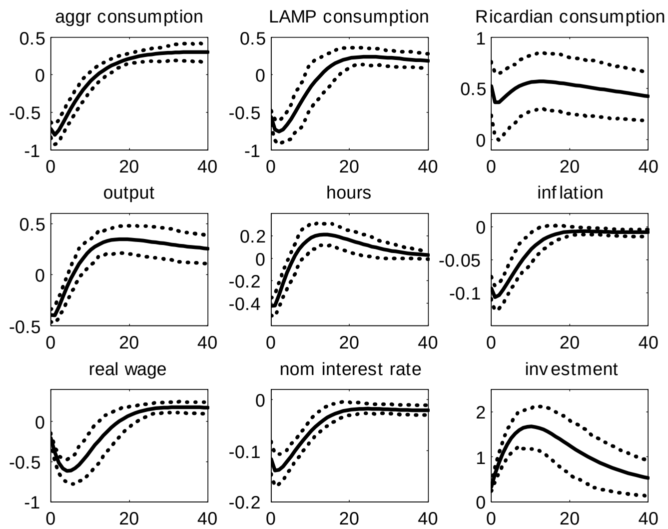

Figure 3. Posterior impulse responses to a LAMP shock. Solid lines: mean responses (LAMP shock specification). Dotted lines: 90% confidence bands.

This shock simulates some aspects of the financial crisis, although it still predicts an increase in investment which was not the case in the recent crisis. It should be noticed however that crisis are usually characterized by different types of turbulences. Other shocks and aspects not represented here might have played important roles for describing all the aspects of a crisis. For example, this model do not consider the banking sector and thus disturbances related to it, which played a crucial role for the evolution of the macroeconomic system.

4.4 Recursive estimates

As a second experiment, we carry out recursive estimates of the structural parameter θ. This is very different with respect to what we presented in the previous section, as this concerns the estimate of the steady state fraction of LAMP, so the underlying component of this share of consumers, while in the previous section we focused on the short run component and its time profile, assuming a constant steady state fraction θ.

We estimate the baseline model starting from 1970:Q2 and we consider in particular the period of the recent crisis. The first sample end-up with 2007:Q1 and we extend each sample estimate by a quarter. The results about the estimate of θ are stored in Table 4.

We find that the fraction of LAMP is very sensible to the sample considered. We observe however that, after a period of rather low values of θ, in 2007:Q4 there has been a first hike which has led the fraction on steadily higher levels, even if we can still observe samples of again low fractions (2009:Q1 and 2009:Q4). However, this could be due the uncertain and troubled period. Then, after two samples of relatively lower fractions (even if not as low as before 2007:Q4), there is second peak which leads again the structural share of LAMP in the Euro area to reach 31-32%.

sample	θ
1970-2007Q1	0.15
1970-2007Q2	0.17
1970-2007Q3	0.09
1970-2007Q4	0.29
1970-2008Q1	0.33
1970-2008Q2	0.23
1970-2008Q3	0.27
1970-2008Q4	0.25
1970-2009Q1	0.16
1970-2009Q2	0.29
1970-2009Q3	0.24
1970-2009Q4	0.15
1970-2010Q1	0.29
1970-2010Q2	0.23
1970-2010Q3	0.31
1970-2010Q4	0.20
1970-2011Q1	0.19
1970-2011Q2	0.31
1970-2011Q3	0.32
1970-2011Q4	0.19

Table 4: Recursive estimates of the fraction of LAMP

These two peaks of θ could be interpreted as a consequence of the periods of financial turmoil first and sovereign debt crisis then, also identified by the CEPR as periods of recession for the Euro Area.

Even if some interpretation of these results can be given, this analysis stresses that it is difficult to state exactly how big is the share of consumers not accessing financial markets. However, it also highlights that these consumers exist, at least in the Euro area, and can also account for a significant share of the population. As a consequence, given the importance they have for the system responses to the different macroeconomic disturbances, policymakers should consider their existence seriously, while adopting targeted measures to face exogenous shocks and stabilize the economy.

5 Conclusions

We develop a medium scale DSGE model with limited asset market participation. We estimate the model for the Euro Area with the standard shocks considered in the literature to gain intuition on the size of the fraction of LAMP and on the estimated responses to shocks. We confirm that LAMP should be considered although it is difficult to state definitely how large is it. In fact, different specifications of the model give different values.

As a second experiment, we assume that the fraction of Non-Ricardian agents is time varying and we estimate its evolution over time and its contribution to consumption growth volatility. We find that LAMP has increased steadily starting from 1992 and accounts for values between 12 and 33% of consumption growth volatility. In particular, it has played an important role during the main phases of crisis identified by the CEPR, but the 2008-2009 downturn, in particular the sovereign debt crisis.

This is a *positive* analysis of limited asset market participation in estimated models for the Euro area, we leave more *normative* analyses for future research.

6 References

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7 Technical Appendix

7.1 Non-linear equations

After deriving the first order conditions for Ricardian agents, unions and firms, we adjust all growing variables for growth to obtain a stationary equilibrium. In this case, lower case letters stand for "adjusted" variables, for example, $y_t = \frac{Y_t}{z_t}$. Notice that $w_t = \frac{W_t}{P_t z_t}$ and $\lambda_t^o = \Lambda_t^o z_t$. We end up the following set of non linear equations:

$$\left(c_t^o\right)^{-\sigma} c_{t-1}^{b(\sigma-1)} \exp\left(\frac{(\sigma-1)\,\varepsilon_t^l}{1+\phi_l} h_t^{1+\phi_l}\right) = \lambda_t^o \left(1+\tau_t^c\right) \tag{19}$$

$$R_t = \pi_{t+1} g_{z,t+1} \frac{\lambda_t^o}{\beta \varepsilon_t^b \lambda_{t+1}^o} \tag{20}$$

$$\begin{aligned} 1 \quad = \quad & Q_t^o \varepsilon_t^i \left\{1 - \gamma_I \left(g_{z,t}\frac{i_t}{i_{t-1}} - g_z\right) g_{z,t}\frac{i_t}{i_{t-1}} - \frac{\gamma_I}{2}\left(g_{z,t}\frac{i_t}{i_{t-1}} - g_z\right)^2\right\} \\ & + g_{z,t+1}\frac{\lambda_{t+1}^o}{\lambda_t^o} Q_{t+1}^o \varepsilon_{t+1}^i \beta \gamma_I \left(g_{z,t+1}\frac{i_{t+1}}{i_t} - g_z\right)\left(\frac{i_{t+1}}{i_t}\right)^2 \end{aligned} \tag{21}$$

$$\frac{1}{g_{z,t+1}} \frac{\lambda_{t+1}^o}{\lambda_t^o} \beta \left\{\left(1-\tau_{t+1}^k\right)\left[r_{t+1}^k u_{t+1} - a\left(u_{t+1}\right)\right] + \tau_{t+1}^k \delta + Q_{t+1}^o \left(1-\delta\right)\right\} = Q_t^o \tag{22}$$

$$r_t^k = \gamma_{u1} + \gamma_{u2}\left(u_t - 1\right) \tag{23}$$

$$k_{t+1} = \left(1-\delta\right)\frac{k_t}{g_{z,t}} + \varepsilon_t^i \left[1 - \frac{\gamma_I}{2}\left(g_{z,t}\frac{i_t}{i_{t-1}} - g_z\right)^2\right] i_t \tag{24}$$

$$\left(1+\tau_t^c\right) c_t^{rt} = \left(1 - \tau_t^l - \tau_t^{wh}\right) w_t h_t + tr_t^{rt} - t_t^{rt} \tag{25}$$

$$g_t + \frac{R_{t-1}}{\pi_t}\frac{b_t}{g_{z,t}} + tr_t = b_{t+1} + t_t + \tau_t^c c_t + \left(\tau_t^l + \tau_t^{wh} + \tau^{wf}\right) w_t h_t + \tau_t^k \left[r_t^k u_t - \left(a\left(u_t\right) + \delta\right)\right]\frac{k_t}{g_{z,t}} \tag{26}$$

$$y_t = c_t + g_t + i_t + \frac{a\left(u_t\right) k_t}{g_{z,t}} \tag{27}$$

$$c_t = \theta_t c_t^{rt} + \left(1-\theta_t\right) c_t^o \tag{28}$$

$$
\begin{aligned}
0 \;=\;& E_t \sum_{s=0}^{\infty} (\xi_w \beta)^s \, c_{t+s-1}^{b(\sigma-1)} \exp\left(\frac{(\sigma-1)\,\varepsilon_{t+s}^{l}}{1+\phi_l} (h_{t+s})^{1+\phi_l}\right) (\tilde{w}_t)^{-\frac{1+\lambda_{t+s}^w}{\lambda_{t+s}^w}} \left(\frac{\pi_{t,t+s-1}^{\chi_w} \bar{\pi}_{t,t+s}^{1-\chi_w}}{w_{t+s}\pi_{t,t+s}}\right)^{-\frac{1+\lambda_{t+s}^w}{\lambda_{t+s}^w}} h_{t+s}^d \cdot \\
&\cdot \left\{ \begin{array}{c} \tilde{w}_t \frac{\left(1-\tau_{t+s}^{l}-\tau_{t+s}^{wh}\right)\pi_{t,t+s-1}^{\chi_w}\bar{\pi}_{t,t+s}^{1-\chi_w}}{\left(1+\tau_{t+s}^{c}\right)\pi_{t,t+s}} \left(1-\frac{1+\lambda_{t+s}^w}{\lambda_{t+s}^w}\right)\left[(1-\theta_t)\left(c_{t+s}^{o}\right)^{-\sigma}+\theta\left(c_{t+s}^{rt}\right)^{-\sigma}\right] \\ +\frac{1+\lambda_{t+s}^w}{\lambda_{t+s}^w}\left[(1-\theta_t)\left(c_{t+s}^{o}\right)^{-\sigma} MRS_{t+s}^{o}+\theta_t\left(c_{t+s}^{rt}\right)^{-\sigma} MRS_{t+s}^{rt}\right] \end{array} \right\}
\end{aligned} \tag{29}
$$

$$
w_t = \left[\xi_w \left(\frac{\pi_{t-1}^{\chi_w}\bar{\pi}_t^{1-\chi_w}}{\pi_t} w_{t-1}\right)^{\frac{1}{\lambda_t^w}} + (1-\xi_w)(\tilde{w}_t)^{\frac{1}{\lambda_t^w}}\right]^{\lambda_t^w} \tag{30}
$$

$$
\frac{u_t k_t}{h_t g_{z,t}} = \frac{\alpha}{(1-\alpha)} \frac{\left(1+\tau^{wf}\right) w_t}{r_t^k} \tag{31}
$$

$$
mc_t = \alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)}\left(\varepsilon_t^a\right)^{-1}\left(r_t^k\right)^{\alpha}\left[\left(1+\tau^{wf}\right)w_t\right]^{1-\alpha} \tag{32}
$$

$$
s_{P,t} y_t = \varepsilon_t^a \left(u_t \frac{k_t}{g_{z,t}}\right)^{\alpha}\left(h_t^d\right)^{1-\alpha} - \Phi \tag{33}
$$

$$
E_t \sum_{s=0}^{\infty}\left(\xi_p\beta\right)^s \varepsilon_t^b \frac{\lambda_{t+s}^o}{\lambda_t^o} y_{t+s}^z \left[\tilde{p}_t^z \frac{\pi_{t,t+s-1}^{\chi_p}\bar{\pi}_{t,t+s}^{1-\chi_p}}{\pi_{t,t+s}}\left(1+\frac{1}{G'^{-1}(\omega_{t+s})}\frac{G'(x_{t+s})}{G''(x_{t+s})}\right) - mc_{t+s}\frac{1}{G'^{-1}(\omega_{t+s})}\frac{G'(x_{t+s})}{G''(x_{t+s})}\right] = 0 \tag{34}
$$

$$
\begin{aligned}
1 \;=\;& \left(1-\xi_p\right)\tilde{p}_t^z G'^{-1}\left(\tilde{p}_t^z \int_0^1 G'\left(\frac{y_t^z}{y_t}\right)\frac{y_t^z}{y_t}dz\right) \\
&+\xi_p \pi_{t-1}^{\chi_p}\bar{\pi}_t^{1-\chi_p}\pi_t^{-1} G'^{-1}\left(\pi_{t-1}^{\chi_p}\bar{\pi}_t^{1-\chi_p}\pi_t^{-1}\int_0^1 G'\left(\frac{y_t^z}{y_t}\right)\frac{y_t^z}{y_t}dz\right)
\end{aligned} \tag{35}
$$

$$
tr_t = \theta tr_t^{rt} + (1-\theta)\, tr_t^{o} \tag{36}
$$

$$
t_t = \theta t_t^{rt} + (1-\theta)\, t_t^{o} \tag{37}
$$

$$
h_t = s_{W,t} h_t^d \tag{38}
$$

$$
s_{W,t} = \int_0^1 \left(\frac{W_t^j}{W_t}\right)^{-\frac{1+\lambda_t^w}{\lambda_t^w}} dj \tag{39}
$$

$$
s_{P,t} = \int_0^1 \left(\frac{P_t^z}{P_t}\right)^{-\frac{1+\lambda_t^p}{\lambda_t^p}} dz \tag{40}
$$

$$MRS_t^o = c_t^o \varepsilon_t^l h_t^{\phi_l} \tag{41}$$

$$MRS_t^{rt} = c_t^{rt} \varepsilon_t^l h_t^{\phi_l} \tag{42}$$

7.2 Set of log-linearized equations

After log-linearizing the model around its non-stochastic steady state and making some algebra, we obtain a system composed by 19 equation and 19 endogenous variables. Hatted variables stand for variables in log deviation from their steady state, for example: $\hat{y}_t = \log\left(\frac{y_t}{y}\right)$. Notice also that fiscal variables, such as government spending, debt, lump sum taxes and transfers has been defined in deviation from steady state output, for example: $\hat{g}_t = \frac{g_t - g}{y}$.

$$\begin{aligned} \hat{c}_t^o &= \hat{c}_{t+1}^o + \frac{(1-\sigma)\,b}{\sigma}\left(\hat{c}_t - \hat{c}_{t-1}\right) - \frac{1}{\sigma}\left(\hat{\varepsilon}_t^b + \hat{R}_t - \hat{\pi}_{t+1} - \hat{g}_{z,t+1}\right) \\ &\quad + \frac{(1-\sigma)\,h^{1+\phi_l}}{\sigma}\left(\hat{h}_{t+1} - \hat{h}_t\right) + \frac{(1-\sigma)\,h^{1+\phi_l}}{(1+\phi_l)\,\sigma}\left(\hat{\varepsilon}_{t+1}^l - \hat{\varepsilon}_t^l\right) \\ &\quad + \frac{1}{\sigma}\frac{\tau^c}{1+\tau^c}\left(\hat{\tau}_{t+1}^c - \hat{\tau}_t^c\right) \end{aligned} \tag{43}$$

$$\begin{aligned} \hat{\imath}_t &= \frac{1}{\gamma_I g_z^2 (1+\beta)}\left(\hat{Q}_t^o + \hat{\varepsilon}_t^i\right) - \frac{1}{1+\beta}\hat{g}_{z,t} + \frac{1}{1+\beta}\hat{\imath}_{t-1} \\ &\quad + \frac{\beta}{1+\beta}\hat{\imath}_{t+1} + \frac{\beta}{1+\beta}\hat{g}_{z,t+1} \end{aligned} \tag{44}$$

$$\begin{aligned} &-\hat{R}_t - \hat{\varepsilon}_t^b + \hat{\pi}_{t+1} + \frac{\beta}{g_z}\left(\delta - r^k\right)\tau^k \hat{\tau}_{t+1}^k + \frac{\beta}{g_z}\left(1-\tau^k\right) r^k \hat{r}_{t+1}^k \\ &+ \frac{\beta}{g_z}(1-\delta)\,\hat{Q}_{t+1}^o = \hat{Q}_t^o \end{aligned} \tag{45}$$

$$\hat{r}_t^k = \frac{\gamma_{u2}}{r^k}\hat{u}_t \tag{46}$$

$$\hat{k}_{t+1} = \frac{(1-\delta)}{g_z}\hat{k}_t + \frac{i}{k}\hat{\imath}_t - \frac{(1-\delta)}{g_z}\hat{g}_{z,t} + \frac{i}{k}\hat{\varepsilon}_t^i \tag{47}$$

$$\begin{aligned} &(1+\tau^c)\frac{c^{rt}}{c}\hat{c}_t^{rt} + \frac{c^{rt}}{c}\tau^c \hat{\tau}_t^c + \frac{wh}{c}\left(\tau^l \hat{\tau}_t^l + \tau^{wh}\hat{\tau}_t^{wh}\right) \\ = \; &\left(1 - \tau^l - \tau^{wh}\right)\frac{wh}{c}\left(\hat{w}_t + \hat{h}_t\right) + \frac{y}{c}\widehat{tr}_t^{rt} - \frac{y}{c}\hat{t}_t^{rt} \end{aligned} \tag{48}$$

$$
\begin{aligned}
& \hat{g}_t + \frac{R}{\pi g_z}\left[\hat{b}_t + \frac{b}{y}\left(\hat{R}_{t-1} - \hat{g}_{z,t} - \hat{\pi}_t\right)\right] + \widehat{tr}_t \\
= \; & \hat{b}_{t+1} + \hat{t}_t + \frac{c}{y}\tau^c\left(\hat{\tau}_t^c + \hat{c}_t\right) \\
& + \frac{wh}{c}\frac{c}{y}\left[\tau^l\hat{\tau}_t^l + \tau^{wh}\hat{\tau}_t^{wh} + \tau^{wf}\hat{\tau}_t^{wf} + \left(\tau^l + \tau^{wh} + \tau^{wf}\right)\left(\hat{w}_t + \hat{h}_t\right)\right] \\
& + \frac{k\tau^k}{yg_z}\left[r^k\hat{r}_t^k + \left(r^k - \gamma_{u1}\right)\hat{u}_t + \left(r^k - \delta\right)\left(\hat{\tau}_t^k + \hat{k}_t - \hat{g}_{z,t}\right)\right]
\end{aligned} \tag{49}
$$

$$
0 = \frac{c}{y}\hat{c}_t + \hat{g}_t + \frac{i}{y}\hat{\imath}_t - \hat{y}_t + \frac{\gamma_{u1}k}{yg_z}\hat{u}_t \tag{50}
$$

$$
\hat{c}_t = \theta\frac{c^{rt}}{c}\hat{c}_t^{rt} + (1-\theta)\frac{c^o}{c}\hat{c}_t^o + \frac{\left(c^{rt} - c^o\right)\theta}{c}\hat{\theta}_t \tag{51}
$$

$$
\widehat{tr}_t = \theta\widehat{tr}_t^{rt} + (1-\theta)\widehat{tr}_t^o + \frac{\left(tr^{rt} - tr^o\right)\theta}{y}\hat{\theta}_t \tag{52}
$$

$$
\hat{t}_t = \theta\hat{t}_t^{rt} + (1-\theta)\hat{t}_t^o + \frac{\left(t^{rt} - t^o\right)\theta}{y}\hat{\theta}_t \tag{53}
$$

$$
\begin{aligned}
\left(1 + \beta\chi_p\right)\hat{\pi}_t \;=\; & \chi_p\hat{\pi}_{t-1} + \beta\hat{\pi}_{t+1} - \beta\left(1 - \chi_p\right)\hat{\overline{\pi}}_{t+1} + \left(1 - \chi_p\right)\hat{\overline{\pi}}_t \\
& + A\frac{\left(1 - \beta\xi_p\right)\left(1 - \xi_p\right)}{\xi_p}\left(\widehat{mc}_t + \hat{\lambda}_t^p\right)
\end{aligned} \tag{54}
$$

$$
\begin{aligned}
\hat{w}_t = & -\frac{(1-\xi_w)(1-\xi_w\beta)}{(1+\beta)\xi_w}\hat{w}_t + \frac{(1-\xi_w)(1-\xi_w\beta)}{(1+\beta)\xi_w}\frac{\lambda^w}{1+\lambda^w}\hat{\lambda}_t^w + \frac{(1-\xi_w)(1-\xi_w\beta)\tau^c}{(1+\beta)\xi_w(1+\tau^c)}\hat{\tau}_t^c \\
& + \frac{(1-\xi_w)(1-\xi_w\beta)\tau^l}{(1+\beta)\xi_w(1-\tau^l-\tau^{wh})}\hat{\tau}_t^l + \frac{(1-\xi_w)(1-\xi_w\beta)\tau^{wh}}{(1+\beta)\xi_w(1-\tau^l-\tau^{wh})}\hat{\tau}_t^{wh} + \frac{(1-\xi_w)(1-\xi_w\beta)\varrho\left(\frac{c^{rt}}{c^o}-1\right)}{(1+\beta)\xi_w(\varpi+1)(1-\theta)(\varrho+1)}\hat{\theta}_t \\
& + \frac{(1-\xi_w)(1-\xi_w\beta)}{(1+\beta)\xi_w(\varpi+1)}\left\{\left[\frac{\sigma\varrho\left(\frac{c^{rt}}{c^o}-1\right)}{(\varrho+1)} + 1\right]\widehat{MRS}_t^o + \left[\varpi - \frac{\sigma\varrho\left(\frac{c^{rt}}{c^o}-1\right)}{(\varrho+1)}\right]\widehat{MRS}_t^{rt}\right\} \\
& + \frac{\beta}{1+\beta}\hat{w}_{t+1} + \frac{1}{1+\beta}\hat{w}_{t-1} + \frac{\chi_w}{1+\beta}\hat{\pi}_{t-1} - \frac{(1+\beta\chi_w)}{1+\beta}\hat{\pi}_t + \frac{\beta}{1+\beta}\hat{\pi}_{t+1} + \frac{(1-\chi_w)}{1+\beta}\hat{\overline{\pi}}_t - \frac{\beta}{1+\beta}(1-\chi_w)\hat{\overline{\pi}}_{t+1}
\end{aligned} \tag{55}
$$

$$
\widehat{MRS}_t^o = \hat{c}_t^o + \phi_l\hat{h}_t + \hat{\varepsilon}_t^l \tag{56}
$$

$$
\widehat{MRS}_t^{rt} = \hat{c}_t^{rt} + \phi_l\hat{h}_t + \hat{\varepsilon}_t^l \tag{57}
$$

$$
\hat{u}_t + \hat{k}_t - \hat{h}_t - \hat{g}_{z,t} = \hat{w}_t - \hat{r}_t^k + \frac{\tau^{wf}}{1+\tau^{wf}}\hat{\tau}_t^{wf} \tag{58}
$$

$$\widehat{mc}_t = -\hat{\varepsilon}_t^a + \alpha \hat{r}_t^k + (1-\alpha)\,\hat{w}_t + (1-\alpha)\,\frac{\tau^{wf}}{1+\tau^{wf}}\hat{\tau}_t^{wf} \tag{59}$$

$$\hat{y}_t = \frac{y+\Phi}{y}\hat{\varepsilon}_t^a + \frac{\alpha\,(y+\Phi)}{y}\hat{k}_t + \frac{\alpha\,(y+\Phi)}{y}\hat{u}_t + \frac{(1-\alpha)\,(y+\Phi)}{y}\hat{h}_t - \alpha\frac{y+\Phi}{y}\hat{g}_{z,t} \tag{60}$$

$$\hat{R}_t = \phi_R \hat{R}_{t-1} + (1-\phi_R)\left(\hat{\overline{\pi}}_t + \phi_\pi\left(\hat{\pi}_{t-1} - \hat{\overline{\pi}}_t\right) + \phi_y \hat{y}_t\right) + \phi_{\Delta\pi}\left(\hat{\pi}_t - \hat{\pi}_{t-1}\right) + \phi_{\Delta y}\left(\hat{y}_t - \hat{y}_{t-1}\right) + \hat{\varepsilon}_t^r \tag{61}$$

with $A = \frac{\left(1+\frac{G''(x)}{G'(x)}\right)}{\left(2+\frac{G'''(x)}{G''(x)}\right)} = \frac{1}{\lambda^p \alpha^p + 1}$ (where λ^p is steady state price markup and α^p is the steady state elasticity of substitution between goods), $\varrho = \frac{\theta}{1-\theta}\left(\frac{c^{rt}}{c^o}\right)^{-\sigma}$ and $\varpi = \varrho\frac{c^{rt}}{c^o}$.

There are several structural shocks, but we estimate only some of them. All remaining shocks and/or fiscal variable not specified are kept constant). The estimated shocks are:

$$\hat{\varepsilon}_t^a = \rho_a \hat{\varepsilon}_{t-1}^a + \eta_t^a$$
$$\hat{\varepsilon}_t^i = \rho_i \hat{\varepsilon}_{t-1}^i + \eta_t^i$$
$$\hat{\varepsilon}_t^r = \rho_r \hat{\varepsilon}_{t-1}^r + \eta_t^r$$
$$\hat{\lambda}_t^p = \rho_p \hat{\lambda}_{t-1}^p + \eta_t^p$$
$$\hat{\lambda}_t^w = \rho_w \hat{\lambda}_{t-1}^w + \eta_t^w$$
$$\hat{\varepsilon}_t^b = \rho_b \hat{\varepsilon}_{t-1}^b + \eta_t^b$$

or

$$\hat{\theta}_t = \rho_\theta \hat{\theta}_{t-1} + \eta_t^\theta$$