

Essays on Asset Pricing and Optimal Policy under Limited Asset Market Participation

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The Equity Premium in a DSGE Model with Limited Asset Market Participation

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Abstract

Models based on the representative agent assumption cannot rationalize observed equity premia. In response to this, exchange economy models have introduced agents heterogeneity, typically in the form of bond and equity holders. We reconsider the issue introducing Limited Asset Market Participation in an otherwise standard medium scale DSGE model. Our model fits financial and macroeconomic data well. We obtain that the correlation between asset holders consumption and financial returns strongly increases in the share of agents excluded from financial markets participation. The predicted unconditional equity premium is therefore large. Further, the strong correlation between dividends and Ricardian households' consumption unambiguously increases precautionary savings and reduces the riskless rate.

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Keywords: asset pricing, equity premium, limited asset market participation, business cycle, DSGE, sticky prices.

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1 Introduction

The standard neoclassical finance model based on intertemporal consumption optimization predicts that assets are priced according to their correlation with aggregate consumption growth, but this latter variable is apparently too smooth for the model to replicate the empirically observed equity premium (Mehra and Prescott, 1985). In response to this, and to other related "puzzles", the production-based asset pricing literature has explored the connection between the stylized facts of the business cycle and the empirical regularities that characterize the financial markets, such as the equity premium, its Sharpe ratio, the risk-free rate and return autocorrelations. Lettau (2003), Jermann (1998), Boldrin, Christiano and Fischer (2001) and Uhlig (2007), have shown that the predicted unconditional risk premium increases if one extends the real business cycle model to account for real frictions. De Paoli, Scott and Weenen (2010) find that nominal rigidities increase the unconditional premium in case of aggregate demand shocks and decrease it in case of aggregate supply shocks. Nevertheless, these models still find it difficult to replicate the relatively large risk premia observed in the data.

Another strand of literature has considered rudimentary real business cycle models where only a subset of households participate in the stock exchange market but access to the bonds market is unrestricted. In this framework shareholders provide partial income insurance to bond holders and, relative to the case of full stock market participation, the concentration of firms capital in their hands raises the correlation between their consumption growth rate and stock returns. This finding is consistent with empirical evidence suggesting that the consumption of stockholders is more volatile than that of non-stockholders and is more highly correlated with the excess return on the stock market (Mankiw and Zeldes, 1991). Polkovnichenko (2004) shows that restricting asset market participation cannot warrant a sufficiently large increase in the theoretical risk premium. In a similar framework, Guvenen (2009) assumes that stock holders are characterized by a relatively large elasticity of intertemporal substitution in consumption. His model can replicate the empirical facts concerning financial variables but predicts excessive volatility in consumption growth and in the labor supply. In addition, the embryonic production side of the model economy does not allow to disentangle the effects of different shocks and frictions in determining financial variables.

This paper is inspired by Weil (1992), who showed that Limited Asset Market Participation (LAMP henceforth) may contribute to solve the empirical equity premium puzzle in endowment models. The LAMP hypothesis implies that only a fraction of consumers participate in financial markets whereas the rest of the population, i.e. the rule-of-thumb or hand-to-mouth consumers (RT consumers, henceforth), do not accumulate any wealth and entirely consume their current income. Here we show that the LAMP hypothesis, already popularized in DSGE models (Gali et al., 2007), allows to strongly improve the fit of the unconditional moments of financial variables in an otherwise standard DSGE model, akin to Smets and Wouters (2007). A number of studies estimate the fraction of RT consumers in a range between 26% and 50%. (Campbell and Mankiw, 1990; Iacoviello, 2004; Coenen and Straub, 2005; Forni, Monteforte, and Sessa, 2009).

In a nutshell, the key message of the paper is that DSGE models characterized by the LAMP hypothesis can replicate key moments of financial variables, while improving over the corresponding representative agent model for what concerns the fit of macroeconomic moments at business cycle frequency. In our model the equity premium essentially arises due to a combination of price stickiness and LAMP. In fact sticky prices cause a redistribution of factor incomes whenever shocks hit the economy. For instance a positive productivity shock raises firms profits and lowers labor incomes (in analogy with the findings in Smets and Wouters, 2007 and in references cited therein). If

wealth is concentrated in the hands of relatively few investors, i. e. the proportion of RT consumers is sufficiently large, the resulting strong correlation between stockholders consumption and profits is sufficient to predict an empirically plausible risk premium. In addition, the large effect of dividends volatility on the standard deviation of Ricardian households' consumption unambiguously increases the precautionary savings and reduces the riskless rate. Thus LAMP greatly improves model fit of both the equity premium and the riskless rate.

Our characterization of the LAMP hypothesis is quite different from De Graeve et al. (2010) who use LAMP to rationalize the risk premia in a DSGE model with flexible prices. Their model economy is populated by three household groups, shareholders, bondholders and workers who do not hold any wealth. The relatively more risk averse workers engage in long term labour contracts with firms. Such contracts generate endogenous wage stickiness and allow mutual risk sharing between workers, bondholders and stockholders. Due to price flexibility and to the mechanism driving wage-setting contracts, the key mechanism generating the risk premium in their model is quite different from ours, where mutual risk sharing between stockholders and non- stockholders is precluded. In fact in their model the negative correlation between a workers' bargaining power shock and the productivity shock is necessary to obtain the covariance between stockholders consumption growth and equity returns which is necessary to replicate risk premiums. This happens because the optimal labour contract they consider does not allow the model to endogenously produce a significant redistribution among agents. One of the most important contributions of this paper is to demonstrate that it is exactly the uninsurable income redistribution generated by the shocks that increases the equity premium in a DSGE model.

We consider two key shocks, an investment specific shock and a TFP shock. In particular, we find that the equity premium is mainly determined by TFP shocks, while investment specific shocks are fundamental to replicate the volatility of other macro data. LAMP and sticky prices are necessary in such a setting because they allow to extract a higher equity premium from a less volatile TFP shock and to fit macro data more easily. We also find that LAMP overturns the result in De Paoli et al (2010) that sticky prices reduce the risk premium generated by supply shocks. This latter result is determined by the redistributive effects of supply shocks that, due to sticky prices, cause a fall in labor demand and in the real wage, thereby inducing a positive correlation between profits and the consumption of asset holders.

The remainder of the paper is organized as follows. Section 2 presents and derives the model. Section 3 presents the impulse responses and the simulation results. Section 4 checks the robustness of the results and runs the sensitivity analysis. Section 5 draws the conclusions and the perspectives for future research.

2 The Model

The key distinction between asset holders and RT consumers concerns intertemporal optimization of consumption decisions. Asset holders take into account future utility when choosing consumption and portfolio composition. RT consumers spend their whole income every period, thus they do not hold any wealth.

Most papers concerned with financial market outcomes use utility specifications which are non-standard in the DSGE literature, where log-utility in consumption is typically adopted. This utility characterization implies coefficients of consumption risk aversion and intertemporal substitution which are coincident and equal to one. Risk aversion must be larger than one to fit the risk premiums, but in a standard separable utility specification this would compromise the dynamic

performance the macroeconomic model, due to the fall in the elasticity of intertemporal substitution and to the much larger wealth effect on labour supply. To avoid these shortcomings, several studies adopt the Epstein Zin format, which allows to disentangle risk aversion from the elasticity of intertemporal substitution (Rudebusch and Swanson, 2011; Binsberger et al., 2010). As an alternative, De Graeve et al. (2010) use the Greenwood Hercowitz Huffman (GHH) utility specification, which eliminates any wealth effect from labour supply.

Here we adopt a King-Plosser-Rebelo (KPR) utility specification, with external consumption habits. KPR utility incorporates log-separable utility as a special case, maintains the wealth effect on labour supply equal to one for any level of relative risk aversion and is compatible with a balanced growth path. Instead of the more standard habit-in-difference specification, we are going to consider the habit-in-ratio specification presented in Abel (1988). The reason for this is that under LAMP external habits in difference can easily generate a negative marginal utility of consumption for RT households. The ratio format allows to avoid this problem. Right from the outset, it should be noted that the non-saparability and the habit-in-ratio assumptions play no role in determining our key results.

In order to solve the model, we make use of the second-order perturbation methods developed by Schmitt-Grohe and Uribe (2004), that allow risk to affect the value of variables in steady state and to study unconditional risk premia.¹

2.1 Households

We assume a continuum of households indexed by i , $i \in [0, 1]$. RT consumers (rt) and asset-holders or Ricardian consumers (o) are defined over the intervals $[0, \psi]$ and $(\psi, 1]$ respectively. All households share the same KPR utility function:

$$U(c_t^i, n_t^i) = \frac{1}{1-\sigma} \left[\frac{c_t^i}{c_{t-1}^i} \left(1 - \theta (n_t^i)^\phi \right) \right]^{1-\sigma} \quad (1)$$

where $n_t^i = [\int_0^1 (n_{h,t}^i)^\frac{\nu-1}{\nu} dh]^\frac{\nu}{\nu-1}$ defines the labor bundle and c_t^i is household i 's consumption level and c_t is aggregate consumption. In the following we shall assume that $\sigma > 1$. Note that this is necessary to capture the spirit of the catching up with the Joneses specification, that is, a coeteris paribus increase in the habit term raises the marginal utility of consumption $U_c(c_t^i, n_t^i)$.²

2.1.1 Ricardian households

The representative Ricardian household has access to financial markets and maximizes her lifetime discounted utility subject to the budget constraint

$$P_t c_t^o + V_t^N B_t^{N,o} + v_t^R P_t B_t^{R,o} + V_t^{eq} S_t^o \leq W_t n_t^o + B_{t-1}^{N,o} + B_{t-1}^{R,o} P_t + (V_t^{eq} + D_t) S_{t-1}^o$$

¹Allowing for time-varying risk premia would require third order perturbation and is outside the scope of this paper.

²Here, as in the rest of the paper, lower case letters denote variables expressed in real terms.

where total dollar expenditures in the consumption good ($P_t c_t^o$), in nominal bonds ($V_t^N B_t^{N,o}$), in indexed bonds ($v_t^R P_t B_t^{R,o}$) and in equity shares ($V_t^{eq} S_t^o$) must not exceed total dollar revenues, given by the sum of labor income ($W_t n_t^o$), nominal bonds ($B_{t-1}^{N,o}$), indexed bonds ($B_{t-1}^{R,o} P_t$) and the payoff of equity ($(V_t^{eq} + D_t) S_{t-1}^o$). Note that V_t^N , V_t^{eq} , P_t , respectively define the dollar prices of nominal bonds, of the equity index and of the consumption good; whilst v_t^R defines the real price of the indexed bond. W_t defines the nominal wage, D_t is the nominal dividend payment received from owned firms. The household chooses consumption, nominal bonds, indexed bonds and equity holdings while delegating the wage choice to a union. As in De Paoli et al (2010), Ricardian households do not invest directly in capital. Investment in capital is carried out at the level of the intermediate firms. Hence dividends contain both extra-profits deriving from monopolistic competition and the normal return on capital. The first order conditions of the problem are:

$$\lambda_t^o = (c_t^o)^{-\sigma} \left(\frac{1 - \theta n_t^\phi}{c_{t-1}^x} \right)^{1-\sigma} \quad (2)$$

$$V_t^{eq} = \beta E_t \left(\frac{\lambda_{t+1}^o V_{t+1}^{eq} + D_{t+1}}{\lambda_t^o \pi_{t+1}} \right)$$

$$v_t^R = \beta E_t \left(\frac{\lambda_{t+1}^o}{\lambda_t^o} \right) \quad (3)$$

$$V_t^N = \frac{1}{R_t^N} = \beta E_t \left(\frac{\lambda_{t+1}^o}{\lambda_t^o} \frac{1}{\pi_{t+1}} \right)$$

$$c_t^o = w_t n_t + \frac{d_t}{1 - \psi} \quad (4)$$

where $\pi_t = \frac{P_t}{P_{t-1}}$ defines the inflation rate and R_t^N the nominal interest rate. The market clearing conditions for the equity and bonds markets are:

$$S_t^o (1 - \psi) = 1$$

$$B_t^{N,o} (1 - \psi) = 0$$

$$B_t^{R,o} (1 - \psi) = 0$$

2.1.2 RT Households

RT households do not optimize and simply consume their labor income each period. Their budget constraint is $P_t c_t^{rt} = W_t n_t$. The marginal utility of consumption for RT households is:

$$\lambda_t^{rt} = (c_t^{rt})^{-\sigma} \left(\frac{1 - \theta n_t^\phi}{c_{t-1}^x} \right)^{1-\sigma} \quad (5)$$

2.2 Aggregation among households

Average marginal utility and aggregate consumption respectively are

$$\lambda_t = \psi \lambda_t^o + (1 - \psi) \lambda_t^{rt} \quad (6)$$

$$c_t = (1 - \psi) c_t^o + \psi c_t^{rt} \quad (7)$$

2.3 Unions

There is one labour union for each differentiated labor type. The representative labour union solves the following problem:³⁴

$$\begin{aligned} & \max E_0 \sum_{t=0}^{\infty} \beta^t [(1 - \psi) U(c_t^o, n_t(W_{h,t})) + \psi U(c_t^{rt}, n_t(W_{h,t}))] \\ \text{s.t. } & P_t c_t^o = \int_0^1 W_{h,t} \left(\frac{W_{h,t}}{W_t} \right)^{-\nu} dh n_t^d + \frac{D_t}{1 - \psi} - \frac{X}{2} \left(\frac{W_{h,t}}{W_{h,t-1}} - 1 \right)^2 P_t n_t^d \\ & P_t c_t^{rt} = \int_0^1 W_{h,t} \left(\frac{W_{h,t}}{W_t} \right)^{-\nu} dh n_t^d - \frac{X}{2} \left(\frac{W_{h,t}}{W_{h,t-1}} - 1 \right)^2 P_t n_t^d \end{aligned}$$

The first order condition is

$$\begin{aligned} - \frac{\psi U_n(c_t^o, n_t) + (1 - \psi) U_n(c_t^{rt}, n_t)}{\lambda_t} &= \frac{\nu - 1}{\nu} w_t + \frac{X}{\nu} (\pi_{W,t} \pi_t - 1) \pi_{W,t} \pi_t \\ & - \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{X}{\nu} (\pi_{W,t+1} \pi_{t+1} - 1) \pi_{W,t+1} \pi_{t+1} \frac{n_{t+1}}{n_t} \right] \end{aligned} \quad (8)$$

where

$$U_n(c_t^i, n_t) = - \left(1 - \theta n_t^\phi \right)^{-\sigma} \left(\frac{c_t^i}{c_{t-1}^i} \right)^{1-\sigma} \theta \phi n_t^{\phi-1} : i = o, rt$$

and $\pi_{W,t}$ is real wage inflation, that is $\frac{W_t}{W_{t-1}} \frac{1}{\pi_t}$. Notice that differently from the Calvo setting there is no wage dispersion in equilibrium, hence $n_t = n_t^d$.

³We assume that the nominal wage adjustment cost is intangible. In section 2.5 we make the same assumption for the price adjustment cost, following De Paoli et al (2010). In a separate exercise, we solved the model with tangible nominal adjustment costs and found that our results are unaffected. The assumption that wage adjustment costs are intangible implies that such costs appear in the budget constraints of agents when unions solve their problem but they do not appear in the problem households.

⁴In the problem below we implicitly define $n_t(W_{h,t}) = \int_0^1 \left(\frac{W_{h,t}}{W_t} \right)^{-\nu} dh n_t^d$.

2.4 Labour packers

Labour packers buy the differentiated labour types from unions and sell the aggregated labour bundle to intermediate goods firms. They maximize profits under a Dixit-Stiglitz production function and operate under perfect competition:

$$\max W_t n_t^d - \int_0^1 W_{h,t} n_{h,t} dh \quad s.t. \quad n_t^d = \left[\int_0^1 n_{h,t}^{\frac{\nu-1}{\nu}} dh \right]^{\frac{\nu}{\nu-1}}$$

The first order conditions are:

$$n_{h,t} = \left(\frac{W_{h,t}}{W_t} \right)^{-\nu} n_t^d \quad (9)$$

$$n_t^d = \left[\int_0^1 n_{h,t}^{\frac{\nu-1}{\nu}} dh \right]^{\frac{\nu}{\nu-1}} \quad (10)$$

Equation (9) is the demand for labour of type h, already shown in section 2.3. Combining it with (10) one gets the wage index $W_t = \left(\int_0^1 W_{h,t}^{1-\nu} dh \right)^{\frac{1}{1-\nu}}$.

2.5 Intermediate Goods Firms

Intermediate firm producing good z maximizes profits subject to a Cobb-Douglas production function and to a downward sloping demand function. It also invests, accumulates capital and is subject to a capital adjustment cost and to a productivity-augmented fixed cost of production modeled as in Justiniano and Primiceri (2010), and chosen so that profits are zero in steady state as in Christiano et al (2005). Finally, it is also subject to a Rotemberg nominal price adjustment cost $\frac{K}{2} \left(\frac{P_{Z,t}}{P_{Z,t-1}} - 1 \right)^2 y_t$. Following the assumptions in De Paoli et al (2010), this cost is intangible, in the sense that it is not subtracted to households income but it does enter the price setting decision. The optimization problem is:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t \lambda_t^o [d_{Z,t} - \frac{K}{2} \left(\frac{P_{Z,t}}{P_{Z,t-1}} - 1 \right)^2 y_t]$$

$$s.t. \quad d_{Z,t} \leq \frac{P_{Z,t}}{P_t} y_{Z,t} - w_t n_{Z,t}^d - i_{Z,t}$$

$$y_{Z,t} \leq A_t (n_{Z,t}^d)^\alpha k_{Z,t-1}^{1-\alpha} - e^g f c$$

$$y_{Z,t} = \left(\frac{P_{Z,t}}{P_t} \right)^{-\mu} y_t$$

$$k_{Z,t} \leq (1 - \delta) k_{Z,t-1} + F_t \omega(i_{Z,t}, k_{Z,t-1}) k_{Z,t-1}$$

where the discount factor $\beta^t \lambda_t^o$ reflects the preferences of firms owners, i.e. the Ricardian households, $k_{Z,t}$ is firm owned capital, A_t is the technology variable that grows at rate g and is subject to AR(1) shocks, such that

$$\begin{aligned}\log A_t &= g + \log A_{t-1} + \eta_t \\ \eta_t &= \rho_\eta \eta_{t-1} + \varepsilon_{\eta,t}\end{aligned}$$

where $\varepsilon_{\eta,t}$ is i.i.d. $N(0, \sigma_\eta^2)$. and $\omega(i_{Z,t}, k_{Z,t-1}) = \frac{a_1}{1 - \frac{1}{X^K}} \left(\frac{i_{Z,t}}{k_{Z,t-1}} \right)^{1 - \frac{1}{X^K}} + a_2$ is the capital adjustment cost according to the specification in Jermann (1998) and Uhlig (2007). In this formulation, X^K represents the elasticity of the investment to capital ratio with respect to Tobin's Q and the capital adjustment cost is a decreasing function of X^K . F_t represents an investment specific shock that affects the relative price of investment goods⁵ and follows the process

$$\log F_t = \rho_F \log F_{t-1} + \varepsilon_{F,t}$$

where $\varepsilon_{F,t}$ is i.i.d. $N(0, \sigma_{F,t}^2)$.

After aggregating among firms and noticing that all of them fix the same price, the first order conditions for the representative intermediate firm are:

$$\begin{aligned}w_t &= mc_t A_t \alpha n_t^{\alpha-1} k_{t-1}^{1-\alpha} \\ q_t &= \frac{1}{F_t \left(a_1 \left(\frac{i_t}{k_{t-1}} \right)^{-\frac{1}{X^K}} \right)} \\ q_t &= E_t \left\{ \beta \frac{\lambda_{t+1}^o}{\lambda_t^o} \left(mc_{t+1} A_{t+1} (1 - \alpha) n_{t+1}^\alpha k_t^{-\alpha} \right. \right. \\ &\quad \left. \left. + q_{t+1} [1 - \delta + F_{t+1} \left(\left(\frac{1}{1 - \frac{1}{X^K}} - 1 \right) a_1 \left(\frac{i_t}{k_t} \right)^{1 - \frac{1}{X^K}} + a_2 \right)] \right) \right\} \\ mc_t &= \frac{\mu - 1}{\mu} + \frac{K}{\mu_t} (\pi_t - 1) \pi_t - \beta E_t \left[\frac{\lambda_{t+1}^o}{\lambda_t^o} \frac{K}{\mu} (\pi_{t+1} - 1) \pi_{t+1} \frac{y_{t+1}}{y_t} \right] \\ y_t &= A_t n_t^\alpha k_{t-1}^{1-\alpha} - e^g f c \\ k_t &= (1 - \delta) k_{t-1} + F_t \omega(i_t, k_{t-1}) k_{t-1}\end{aligned}$$

$$d_t = y_t - w_t n_t - i_t$$

⁵Furlanetto and Seneca (2013) investigate the effects of investment-specific shocks under LAMP.

2.6 Final good firms

Final good firms operate under perfect competition. They aggregate differentiated goods produced by intermediate goods firms and maximize profits subject to a production function of the Dixit-Stiglitz type. The optimization problem is

$$\max P_t y_t - \int_0^1 P_{Z,t} y_{Z,t} dz \quad s.t. \quad y_t = \left[\int_0^1 y_{Z,t}^{\frac{\mu-1}{\mu}} dz \right]^{\frac{\mu}{\mu-1}}$$

The first order conditions read as follows:

$$y_{Z,t} = \left(\frac{P_{Z,t}}{P_t} \right)^{-\mu} y_t \quad (11)$$

$$y_t = \left[\int_0^1 y_{Z,t}^{\frac{\mu-1}{\mu}} dz \right]^{\frac{\mu}{\mu-1}} \quad (12)$$

Equation (11) is the downward sloping demand function for good z . After combining it with (12), one gets the price index $P_t = \left[\int_0^1 P_{Z,t}^{1-\mu} dz \right]^{\frac{1}{1-\mu}}$.

2.7 Monetary policy

The central bank sets the nominal interest rate following a Taylor rule

$$\log R_t^N - \log R^{ss} = \theta^\Pi \log \pi_t \quad (13)$$

3 Results

3.1 The theoretical effect of LAMP on asset returns⁶

The second order approximations to the steady state values for the riskless rate, $r^R = \frac{1}{\bar{v}^R}$, and for the equity risk premium, r^p , are

$$\begin{aligned} r^R &= E \ln r_t^R = \ln \frac{1}{\beta} + (\sigma - \chi(\sigma - 1))g - \frac{\sigma^2}{2} var_{c^o} \\ &\quad + \frac{\theta \bar{n}^\phi (\sigma - 1)\sigma}{1 - \theta \bar{n}^\phi} \left(cov_{c^o, n} - \frac{(\sigma - 1)}{2\sigma} var_n \right) \end{aligned} \quad (14)$$

$$r^p = \frac{1}{\beta} \left(\sigma cov_{c^o, r^{eq}} - \frac{\theta \bar{n}^\phi}{1 - \theta \bar{n}^\phi} (\sigma - 1) \phi cov_{n, r^{eq}} \right) \quad (15)$$

where $r^p = E [r_t^{eq} - r_t^R]$, and var_{c^o} , $cov_{c^o, n}$, var_n , $cov_{c^o, r^{eq}}$, $cov_{n, r^{eq}}$ respectively define conditional moments of variables deviations from the deterministic steady state.^{7,8} Interpretation of (14) and

⁶See Appendix A for a derivation of the results presented in this section.

⁷As discussed in section 3.2.1 below, we normalize θ , so that $\bar{n} = 1$. In this case we obtain $\frac{\theta \bar{n}^\phi}{1 - \theta \bar{n}^\phi} \simeq 0.77$. Note that changing the normalization for steady state labor does not affect the above steady state ratio. With $\bar{n} = 0.25$, for instance, we get again $\frac{\theta \bar{n}^\phi}{1 - \theta \bar{n}^\phi} \simeq 0.77$.

⁸Variable \bar{x} defines the value of x in the deterministic steady state

(15) is straightforward and fully consistent with textbook asset pricing theory based on the stochastic discount factor approach. Thus variables g and var_{c^o} have opposite effects on r^R because faster consumption growth induces Ricardian households to reduce their savings, whereas consumption volatility raises precautionary savings. An increase in the habit parameter delivers the standard result that savings grow (r^R falls) as long as habits raise the marginal utility of current consumption, i.e. $\sigma > 1$. A positive value of $cov_{c^o,req}$ is obviously associated to a positive risk premium.

Finally, we look at the less familiar effects of employment on asset returns, due to the introduction of non-separability between consumption and leisure. From (2) it is easy to see that an increase in worked hours raises the marginal utility of consumption, λ_t^o . Thus an increase in var_n unambiguously raises the conditional expectation of λ_t^o , causing an increase in savings and a fall in r^R . The term $cov_{c^o,n}$ has the opposite effect because a positive comovement between expected consumption and labor effort dampens the negative effect of expected consumption growth on $E_t \{\lambda_{t+1}^o\}$. A negative value for $cov_{n,req}$ raises r^p because it lowers the covariance between λ_{t+1}^o and r_{t+1}^{eq} .

Note that LAMP modifies the effect that volatility of macro variables has on asset returns:

$$\begin{aligned} var_{c^o} &= \left(\frac{\bar{c}}{\bar{c}^o}\right)^2 var_c + \left(\frac{\psi}{1-\psi}\right)^2 \left(\frac{\bar{d}}{\bar{c}^o}\right)^2 var_d + 2 \left(\frac{\bar{c}}{\bar{c}^o}\right) \left(\frac{\psi}{1-\psi}\right) \left(\frac{\bar{d}}{\bar{c}^o}\right) cov_{c,d} \\ cov_{c^o,n} &= \left(\frac{\bar{c}}{\bar{c}^o}\right) cov_{c,n} + \left(\frac{\psi}{1-\psi}\right) \left(\frac{\bar{d}}{\bar{c}^o}\right) cov_{n,d} \\ cov_{c^o,req} &= \frac{\bar{c}}{\bar{c}^o} cov_{c,req} + \frac{\psi}{1-\psi} \frac{\bar{d}}{\bar{c}^o} cov_{d,req} \end{aligned} \quad (16)$$

$$\text{where } \frac{\bar{c}}{\bar{c}^o} = 1 - \psi + \frac{1}{1 + \frac{\bar{d}}{(1-\psi)\bar{w}}}, \quad \frac{\bar{d}}{\bar{c}^o} = \frac{1-\psi}{\frac{\bar{w}}{d}(1-\psi) + 1}, \quad \frac{\bar{d}}{\bar{w}} = \bar{n} \left[\frac{1-\alpha}{\alpha} - \frac{\delta^{\frac{1-\beta(1-\delta)}{\beta(1-\alpha)}} \left(\frac{\mu}{\mu-1}\right)^2}{\alpha} \right]$$

It is easy to see that an increase in ψ unambiguously lowers the impact of consumption volatility and consumption-employment covariance, and raises the importance of dividends, whose effect on the consumption marginal utility of Ricardians is increasing in ψ .

To highlight differences between our approach and previous contributions such as De Graeve et al. (2010) we rearrange the equity premium as follows

$$r^p = \frac{1}{\beta} (-cov_{z,req} - cov_{\lambda,req}) \quad (17)$$

where $z_t = \ln \lambda_t^o - \ln \lambda_t$; $\lambda_t = (1-\psi)\lambda_t^o + \psi\lambda_t^{rt}$. In De Graeve et al (2010), prices are flexible and the labour contract is such that $cov_{z,req} = 0$ in the absence of exogenous redistributive shocks. To replicate the empirical risk premium it is therefore necessary to assume that redistributive shocks are negatively correlated with the productivity shock, which ensures that full risk sharing is precluded and the consumption marginal utility of workers falls with respect to the consumption marginal utility of firms owners.

3.2 Numerical simulations

Log-linearization is not well suited for analyzing risk premia, since it produces results characterized by certainty equivalence, where investors behave as if they were risk neutral and all assets have

the same price. The literature has therefore relied on alternative solution methods. While global solution methods, such as value function iteration and projection methods, allow to take into account non-linearities, they are not able to deal with models with many state variables because they suffer from the curse of dimensionality. So, we shall solve the model using second order perturbation methods, as in Schmitt-Grohe and Uribe (2004).⁹

3.2.1 Calibration

The baseline calibration of the parameters is reported in Table 1. Following De Paoli et al (2010) we set the discount factor β at $1/1.01$, the coefficient σ at 5,¹⁰ the quarterly capital depreciation rate δ at 0.025 and the Rotemberg parameters for wage and price stickiness at 77, such that if a Calvo model was used instead, prices and nominal wage would be adjusted every 4.5 quarters.¹¹ Following De Graeve et al (2010) we set $\alpha = 70\%$ and the the Frisch elasticity at about 1.3.¹² Differently from De Graeve et al (2010) we assume that all agents have the same coefficient of relative risk aversion. The parameter for external habit formation χ is set to 0.7, well in the range found in the empirical literature (see Dennis, 2009). Parameter X^K , crucial to introduce investment adjustment costs, is set at 0.23, as in Jermann (1998). As in Christiano et al (2005) and De Graeve et al (2010), fixed cost fc represents the 20% of steady state output, therefore to obtain zero profits in the deterministic steady state we set $\mu = 6$. We also set $\nu = 6$, obtaining identical wage markups. Parameter θ is set such that hours are normalized to 1 in the deterministic steady state. The share of RT consumers is 40%, within the range estimated in the literature reported in the introduction. As for the shock persistence parameters, we set $\rho_\eta = 0.95$ (De Paoli et al., 2010) and $\rho_f = 0.73$ (Justiniano et al, 2010). The inflation parameter in the Taylor rule, θ^Π , is equal to 1.5. Throughout, we assume a stationary economy, that is $g = 0$.

⁹To solve the model we use the Dynare package.

¹⁰A coefficient $\sigma = 5$ is inconsistent with empirical findings about consumption-labor complementarities (see Chetty, 2006). Avoiding this problem would force us to abandon the expected utility setting. We highlight the effect of labor-consumption complementarity on our results when we report the effect of non separability on risk premia and asset returns.

¹¹Such frequency is not far from estimates in the literature, see Colciago (2011) and Smets and Wouters (2007). Keen and Wang (2007) show how to convert a Calvo parameter into a Rotemberg parameter.

¹²Notice that in the KPR case the Frisch elasticity is $\frac{1}{\phi \left(1 + \frac{\theta \bar{\pi}_{ss}^\phi}{1 - \theta \bar{\pi}_{ss}^\phi} \right) - 1}$ while in the GHH case considered by De Graeve et al it is $\frac{1}{\phi - 1}$. Given our calibration for $\bar{\pi}$ and θ we must set $\phi = 1$.

Parameter	Value	Description	Target/Source
β	1/1.01	Discount Factor	Annual Real Rate 4%
σ	5	Inverse IES	De Paoli et al (2010)
ϕ	1	Leisure Curvature	Frisch Elasticity 1.3
θ	0.43	Leisure Parameter	$\bar{n} = 1$
χ	0.7	Habits	Dennis (2009)
α	0.7	Capital Share	De Graeve et al (2010)
X^K	0.23	Capital adj. Cost	Jermann (1998)
K	77	Price Stickiness	Adj. frequency 4.5 quarters
X	77	Wage Stickiness	Adj. frequency 4.5 quarters
δ	0.025	Capital Depreciation	
ν	6	Labor types CES	20% mark-up
μ	6	Goods CES	20% mark-up
θ^Π	1.5	Taylor Parameter	
a_1 and a_2	$\delta \frac{1}{x^k}$ and 0.03	Capital adj. Cost	No Adj. Cost in SS
ψ	0.4	Share of RT	See Introduction
fc	$\frac{1}{\mu-1}\bar{y}$	Fixed Cost	Zero Profits in SS
ρ_η	0.95	AR TFP	De Paoli et al (2010)
ρ_F	0.73	AR investment	Justiniano et al (2010)
π^{ss}	1	Trend Inflation	
g	0	Trend Growth	

Table 1: Parameters' calibration

3.3 Impulse response functions

Figures 1 and 2 report the percentage response of some macroeconomic variables to 1% TFP and investment-specific shocks under both LAMP and full asset market participation. Figures 3 and 4 show the responses of agent specific consumption. The TFP shock produces an increase in output and consumption but a decrease in hours worked and in real marginal costs. Inflation falls as a consequence. The investment specific shock, instead, produces positive comovement between output, hours worked and real marginal costs. It is easy to see that for both shocks LAMP makes relatively little difference for output, aggregate consumption and worked hours, but we observe a relatively stronger response in investment and real marginal costs.

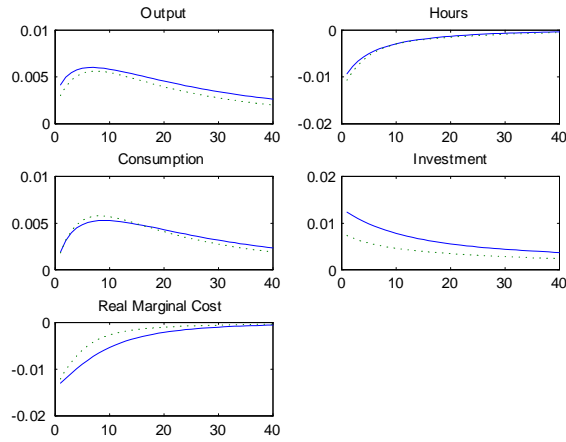


Figure 1: Percentage response to a TFP shock. Blue line: LAMP model. Dotted line: Representative agent model.

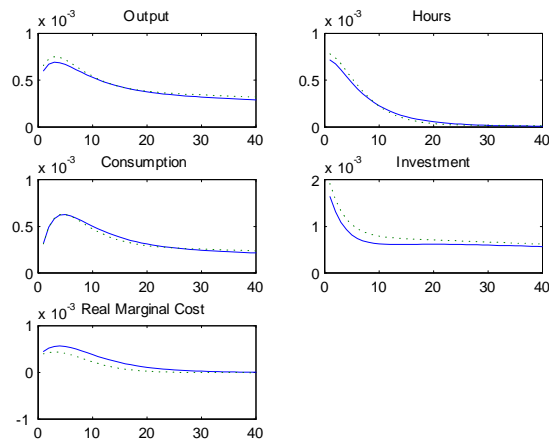


Figure 2: Percentage response to an investment specific shock. Blue line: LAMP model. Dotted line: Representative agent model.

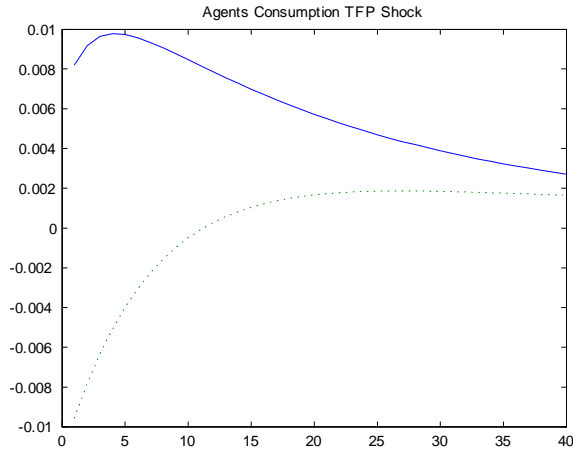


Figure 3: Percentage response to a TFP shock. Blue line: ricardian agents consumption. Dotted line: RT agents consumption.

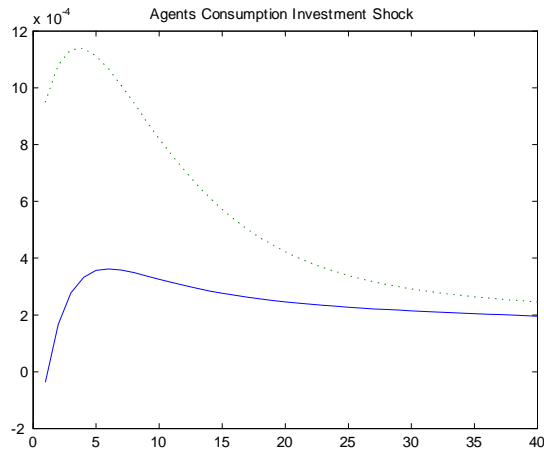


Figure 4: Percentage response to an investment specific shock. Blue line: ricardian agents consumption. Dotted line: RT agents consumption.

To understand these latter effects note that under full asset market participation the fall in labor demand, caused by price stickiness, is associated to a labor income reduction that is fully compensated for by the increase in firms profits. By contrast, under LAMP, the same labor income fall is associated to an income redistribution between Ricardians (whose income and consumption grow) and RTs, whose income and consumption fall. From eq.(2), (5), (6) and (8) it is easy to see that any increase in the dispersion of consumption marginal utilities has a disciplining effect on the real wage. As a consequence, under LAMP we observe a stronger reduction in labor income and in real marginal costs. Note that Ricardian households increase their investment in reaction to the favorable income redistribution caused by the shock. The investment-specific shock has exactly

the opposite effect. Under LAMP the increase in labor demand has a stronger effect on the real wage and on real marginal costs. Due to price stickiness, the real wage rate entails an unfavorable income redistribution for Ricardian consumers, who are therefore induced to reduce investments.

In Figures 5 and 6 we plot IRFs for financial variables, that is, the real riskless rate, the real return on equity r^{eq} , the consumption value of the equity index, real dividends and the stochastic discount factor. It is easy to see that the TFP shock causes pro-cyclical movements of equity returns, while the investment specific shock makes stock returns move counter-cyclically. Under the representative agent model this implies that stocks require a premium for fluctuations linked to productivity but they insure the agent against fluctuations due to investment shocks. The premium linked to investment specific shocks is therefore negative, absent the effect of hours due to non-separability. As pointed out above, under LAMP the TFP shock causes an increase in savings and therefore a fall in the riskless rate. The stronger fall in real marginal costs is associated with a persistent increase in expected dividends. This, in turn, causes an overreaction of the equity index. LAMP unambiguously raises the positive correlation between Ricardian consumption and the return on equity caused by the TFP shock.

Following an investment specific shock, LAMP causes a stronger reaction of marginal costs that triggers a larger fall in dividends, in the equity index and in the return on equity. The consumption of Ricardian agents slightly falls at the moment of the shock and then increases less than aggregate consumption. In spite of consumption dynamics, the inverse relation between the stochastic discount factor and equity returns is now stronger, and LAMP makes sure that the investment shock commands a positive equity premium, even if smaller than that due to TFP shocks.¹³

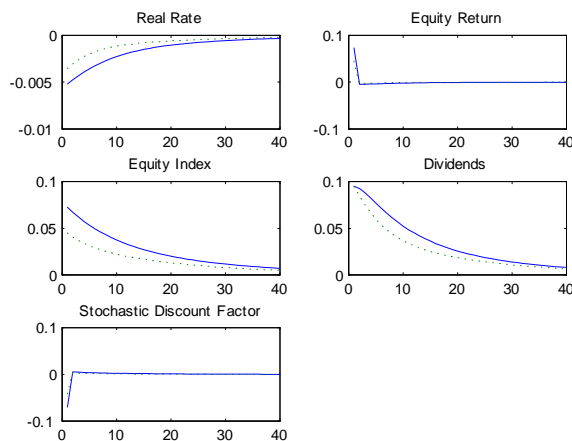


Figure 5: Percentage response to an investment specific shock. Blue line: LAMP model. Dotted line: Representative agent model.

¹³This result is due to the effect of hours on consumption marginal utility. The contribution of the investment-specific shock to the overall equity premium remains small (see our discussion below).

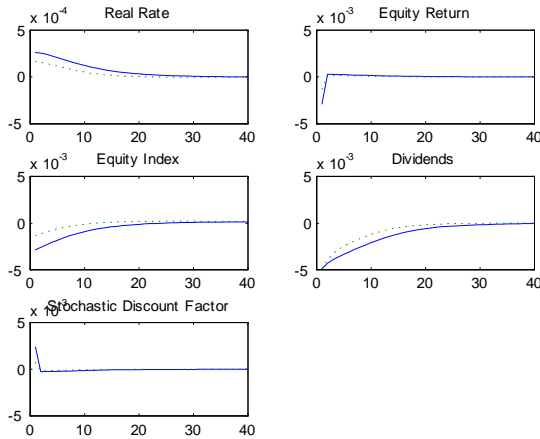


Figure 6: Percentage response to an investment specific shock. Blue line: LAMP model. Dotted line: Representative agent model.

Summarizing our results, introduction of the LAMP hypothesis seems to have a rather modest effect on aggregate variables such as output, hours, aggregate consumption. We do observe more important effects on real marginal costs and investment, due to the redistributive effects of the shocks. LAMP-induced income redistribution has important implications for financial variables: relative to full asset market participation, the correlation between Ricardian agents' consumption and equity return increases.

3.4 Simulated macroeconomic and financial statistics

Prediction of macroeconomic and financial variables requires that, in addition to the parameter values reported in Table 1 we calibrate standard deviations of TFP and investment specific shocks. We experiment with three different alternatives. In the benchmark case, we take $\sigma_\eta = 0.01$ from De Paoli et al. (2010), and $\sigma_F = 0.06$ from Justiniano et al (2010). The second and the third alternatives are based on the Simulated Method of Moments (SMM henceforth), as presented in Ruge-Murcia (2012). The SMM approach consists in picking parameter values to minimize a loss function $L = g(b)^T W g(b)$ where $g(b)$ is a column vector containing the difference between simulated moments and data generated moments as a function of the parameters in vector b and W is a weighting matrix.

In the second calibration, vector b contains the standard deviations σ_η and σ_F , which are selected in order to match US output growth volatility (about 1.06 on a quarterly basis) and the average yearly equity premium (about 5.1, as documented in Shiller (2013)) over the period 1950-2007.¹⁴ In the third experiment the share of RT consumers ψ is endogeneized and included in b . In addition to the equity premium and output growth volatility, vector $g(b)$ includes the standard deviations of investment, consumption, and hours, the level and standard deviation of the riskless rate, the standard deviation of equity returns and the correlations of the latter with consumption and hours.

¹⁴The data sources and the details of raw data transformations are described in the Appendix B.

Notice that our third exercise implements a grid search on ψ , σ_η and σ_F such that observed values for var_y , r^p are obtained and the model fit of the other macroeconomic and financial statistics in $g(b)$ is maximized.

In table 2 we report shock standard deviation values. Note that when the SMM method is used to obtain an endogenous share of RT consumers we obtain $\psi \simeq 0.61$. Thus, for a DSGE model to match the risk premium the value ψ is much larger than what is typically obtained in empirical DSGE models that neglect financial variables.¹⁵ Our calibrations of σ_η are in the range usually considered in the literature (see Canova and Paustian (2011)). Our calibrations of σ_F are indeed larger than the estimates presented in Justiniano et al (2010), who consider a number of additional shocks. We also experimented with these other shocks, finding that their main contribution would be to match volatility of macroeconomic variables, with very limited effects on financial statistics.¹⁶ In a sense, the σ_F calibration adopted here proxies for the effects of these other shocks on the volatility of macroeconomic variables.

Shocks calibration		
	σ_η productivity shock	σ_F investment shock
Literature Calibration	0.01	0.06
SMM constrained ($\psi = 0.4$)	0.0146	0.1421
SMM unconstrained ($\psi \simeq 0.61$)	0.0085	0.1739

Table 2 - Shocks standard deviation

	σ_y	$\frac{\sigma_{inv}}{\sigma_y}$	$\frac{\sigma_c}{\sigma_y}$	$\frac{\sigma_n}{\sigma_y}$	$\rho_{y,inv}$	$\rho_{y,c}$	$\rho_{y,n}$
US data 1950-2007	1.06	2.88	0.77	1.98	0.7	0.81	0.89
Model							
Literature Calibration $\psi = 0.4$	0.56	2.86	0.61	1.89	0.93	0.89	-0.35
Literature Calibration $\psi = 0$	0.52	2.68	0.68	2.32	0.90	0.89	-0.16
SMM constrained $\psi = 0.4$	1.06	2.83	0.62	1.64	0.93	0.89	0.05
SMM unconstrained $\psi = 0.61$	1.06	2.75	0.65	1.25	0.92	0.9	0.53

Table 3 - All moments are quarterly. Data: see Appendix B.

Unconditional moments	$E[R_{t+1}^{eq} - R_t^R]$	ER_t^R	σ_{rr}	σ_{req}	$\rho_{req,c}$	$\rho_{req,n}$
US data 1950-2007	5.1	1.02	2.36	15.02	0.05	-0.19
Model						
Literature Calibration $\psi = 0.4$	2.23	3.04	2.75	15.35	0.35	-0.98
Literature Calibration $\psi = 0$	0.78	3.72	1.61	9.32	0.35	-0.97
SMM constrained $\psi = 0.4$	5.1	1.76	4.29	23.39	0.11	-0.96
SMM unconstrained $\psi = 0.61$	5.1	1.68	4.34	22.94	-0.29	-0.95

Table 4 - All moments are yearly. The standard deviations are 200 times the quarterly model concept. Data: see Appendix B.

Under standard shock calibrations (experiment 1), LAMP allows to increase the equity premium from 0.78 to 2.23. Such an increase is notable, as the standard deviation of output is almost the same as under the representative agent model and half that of the data.

¹⁵As mentioned in the introduction, see Campbell and Mankiw (1990), Coenen and Straub (2005) and Forni, Monteforte, and Sessa (2009).

¹⁶Results available upon request.

Consider now the SMM experiments. In the case where ψ is constrained to be 0.4 the model behaves sufficiently well for what concerns most moments, but it overestimates the volatility of the riskless rate and of the equity return. The correlations of hours with output and equity returns appear to be the most difficult moments to match. The first is strongly positive in the data (0.89), while it is only 0.05 in the model. Table 5, which reports the decomposition of output variance and of the equity premium, helps to get this point. The investment specific shock is the main determinant of output volatility, accounting for 65.6% of it, but its role is pretty small for what concerns the equity premium (11.42%). The TFP shock is necessary to account for the equity premium, but since this shock produces a counterfactually negative correlation between worked hours and output, the latter statistic is difficult to match. In other words, replicating the equity premium and the correlation between hours and output at the same time is difficult because the TFP shock, which is crucial to fulfill the first task, obstacles the accomplishment of the second.

The correlation of hours with equity returns is negative in the data (-0.19), but the model exaggerates this feature and produces a strongly negative correlation (-0.96). Since both shocks tend to produce a negative covariance between the two variables, such difficulty should not surprise. Other shocks are probably needed to better match the latter statistics.

In our third experiment we obtain a strong enhancement of the model-implied correlation of hours with output, which grows from 0.05 to 0.53. The ability to replicate other moments is not particularly affected, apart from a worsening of the fit of hours volatility, which goes from 1.64 to 1.25 and of the correlation of consumption with equity returns, which turns negative and falls from 0.1 to -0.29. The reason for the relatively high value of ψ is that a high share of RT consumers increases the income-redistribution effect of shocks and therefore raises the equity premium, while overall macroeconomic volatility is marginally affected. The higher value of ψ allows to replicate the equity premium with a lower variance of the TFP shock, which in turn generates a better fit of hours-output correlation. The role of the investment specific shock in the economy is now larger. Its contribution to var_y and r^p respectively amounts to 79.33% and 42.83%. This bigger role of the investment specific shock has a cost, anyhow, which is due to the fact that aggregate consumption and stock returns respond in opposite directions and their correlation turns negative.

	Output Variance Decomposition		RP Decomposition	
	TFP Shock	Investment Shock	TFP Shock	Investment Shock
Literature Calibration $\psi = 0.4$	57.98	42.02	95.13	4.87
Literature Calibration $\psi = 0$	41.06	58.94	97.65	2.35
SMM constrained ($\psi = 0.4$)	34.40	65.60	88.58	11.42
SMM unconstrained ($\psi \simeq 0.61$)	20.67	79.33	57.17	42.83

Table 5 - Output variance and equity premium decomposition

Table 6, 7 and 8 report respectively the decomposition of the equity premium in (15), the decomposition of the riskless rate in (14) and, again, the decomposition of the equity premium in (17).

	$\frac{1}{\beta}\sigma\overline{c}COV_{c^o,req}$	$\frac{1}{\beta}\sigma\frac{\psi}{1-\psi}\frac{\overline{d}}{\overline{c^o}}COV_{d,req}$	$-\frac{1}{\beta}\frac{\theta\overline{n}^\phi}{1-\theta\overline{n}^\phi}(\sigma-1)\phi COV_{n,req}$
RP Decomposition	$\frac{1}{\beta}\sigma\frac{\overline{c}}{\overline{c^o}}COV_{c,req}$		
Literature Calibration $\psi = 0.4$	9.04%	47.11%	43.85%
SMM constrained ($\psi = 0.4$)	4.06%	48.66%	47.29%
SMM unconstrained ($\psi \simeq 0.61$)	-7.91%	72.32%	35.59%

Table 6 - Percentage contributions to the equity premium.

	$-\frac{\sigma^2}{2}var_{c^o}$	$\frac{\theta\overline{n}^\phi(\sigma-1)\sigma}{1-\theta\overline{n}^\phi}COV_{c^o,n}$	$-\frac{\theta\overline{n}^\phi(\sigma-1)\sigma}{1-\theta\overline{n}^\phi}\frac{(\sigma-1)}{2\sigma}var_n$
Riskless Rate Decomposition			
Literature Calibration $\psi = 0.4$	31.10%	44.56%	24.34%
SMM constrained ($\psi = 0.4$)	28.9%	42.15%	28.95%
SMM unconstrained ($\psi \simeq 0.61$)	42.23%	40.9%	16.87%

Table 7a - Percentage contributions to the precautionary savings motive.

	$-\frac{\sigma^2}{2}var_{c^o}$	$-\frac{\sigma^2}{2}\left(\frac{\overline{c}}{\overline{c^o}}\right)^2var_c$	$-\frac{\sigma^2}{2}\left(\frac{\psi}{1-\psi}\right)^2\left(\frac{\overline{d}}{\overline{c^o}}\right)^2var_d$	$-\sigma^2\left(\frac{\overline{c}}{\overline{c^o}}\right)\left(\frac{\psi}{1-\psi}\right)\left(\frac{\overline{d}}{\overline{c^o}}\right)COV_{c,d}$
Riskless Rate Decomp.				
Literature Calibration $\psi = 0.4$	9.19%	67.65%	23.16%	
SMM constrained ($\psi = 0.4$)	16.69%	77.06%	6.25%	
SMM unconstrained ($\psi \simeq 0.61$)	11.12%	120.11%	-31.23%	

Table 7b - Percentage contributions to the term $-\frac{\sigma^2}{2}var_{c^o}$

	$\frac{\theta\overline{n}^\phi(\sigma-1)\sigma}{1-\theta\overline{n}^\phi}COV_{c^o,n}$	$\frac{\theta\overline{n}^\phi(\sigma-1)\sigma}{1-\theta\overline{n}^\phi}\left(\frac{\overline{c}}{\overline{c^o}}\right)COV_{c,n}$	$\frac{\theta\overline{n}^\phi(\sigma-1)\sigma}{1-\theta\overline{n}^\phi}\left(\frac{\psi}{1-\psi}\right)\left(\frac{\overline{d}}{\overline{c^o}}\right)COV_{n,d}$
Riskless Rate Decomp.			
Literature Calibration $\psi = 0.4$	11.37%	88.63%	
SMM constrained ($\psi = 0.4$)	-4.4%	104.4%	
SMM unconstrained ($\psi \simeq 0.61$)	-24.3%	124.3%	

Table 7c - Percentage contributions to the term $\frac{\theta\overline{n}^\phi(\sigma-1)\sigma}{1-\theta\overline{n}^\phi}COV_{c^o,n}$

	$-\frac{1}{\beta}COV_{\lambda,req}$	$-\frac{1}{\beta}COV_{z,req}$
RP Decomposition		
Literature Calibration $\psi = 0.4$	18.15%	81.85%
SMM constrained ($\psi = 0.4$)	14.79%	85.21%
SMM unconstrained ($\psi \simeq 0.61$)	-16.2%	116.2%

Table 8 - Percentage contributions to the equity premium.

Under all calibrations, most of the predicted equity premium comes from agent-specific risks such as the covariance between dividends and equity returns. Another important component comes from the term concerning non separability between consumption and labor effort, whereas the influence of the covariance between aggregate consumption and equity returns is almost absent. The latter, indeed, contributes to the equity premium only for about 4% and 9% under the first two experiments, while with ψ endogenous its effect turns negative (-7.91%). The term $COV_{d,req}$, that would not be present under full asset market participation, contributes for about a half of the

equity premium in the first and second experiment and for 72.32% in the third one, confirming that redistribution is the main factor driving our results.

The contribution of consumption-labor non-separability falls when ψ is endogenized. This result can be well appreciated by considering the equity premium decomposition (17) (Table 8). In this case the equity premium is decomposed into two risk factors. The first one is the covariance between average marginal utility of consumption and equity returns. The second one is the risk due to fluctuations of the ratio between the marginal utility of Ricardians and average marginal utility ($cov_{z,req}$). Notice that the term $cov_{z,req}$ would be equal to zero in the absence of redistribution or under perfect risk sharing as relative marginal utility would be constant. Hence, term $-\frac{1}{\beta}cov_{z,req}$ measures the effect of redistribution on the equity premium. Such an effect is clearly dominant, indeed it always explains more than 80% of the equity premium, and its effect is even larger than 100% when ψ is endogenous.¹⁷ Here we can also compare our results to De Graeve et al (2010). In their model, there is a labor contract that allows for perfect risk sharing between asset holders and non asset holders. In that case z_t would be constant and $cov_{z,req} = 0$. To replicate the equity premium De Graeve et al (2010) have to introduce an exogenous shock to z_t , obtaining an estimated negative correlation between z_t and the TFP shock. We can interpret our model as an endogeneization of the redistributive shocks.

3.4.1 Precautionary savings and the riskless rate

From Table 4 it is easy to see that under experiments 2 and 3 LAMP considerably lowers the predicted riskless rate, bringing it close to its observed value. Using (14) and (16) we highlight the determinants of the precautionary savings effect on the average riskless rate (Table 7). Precautionary savings are due to the conditional variance of Ricardian households consumption, the conditional variance of hours and the conditional covariance of their consumption with hours. In all experiments, the three motives are almost equally weighted, with the latter being less important when ψ is endogenous. In addition, we decompose asset holders consumption variance in terms of aggregate consumption, dividends and covariance between the two. As can be observed, most of the consumption uncertainty depends on dividends volatility, which suggests the important role played by redistribution in increasing the precautionary saving motive and reducing the riskless rate.

4 Sensitivity Analysis of the Model

Tables 9 and 10 report the sensitivity of our result to variations in the habit parameter, in the Frisch elasticity, in the capital adjustment cost and in the Rotemberg parameters. In all experiments, we keep the literature calibration for shocks and for ψ .

4.1 Nominal Rigidities

When prices are flexible and only wages are sticky, the equity premium falls from 2.23 to 1.31, notwithstanding a strong increase in output volatility (σ_y almost doubles). The model with flexible nominal wages and sticky prices, on the contrary, delivers almost the same premium of the benchmark model, even if the share of RT consumers is set to 0.2 to insure determinacy. Such statistics suggest that the fundamental nominal rigidity driving our results is price stickiness, not

¹⁷In this latter case the contribution of average marginal utility gets negative.

wage stickiness. This is in sharp contrast with the previous finding that price stickiness *decreases* the premium in representative agent models (De Paoli et al., 2010).

Price rigidities make firms mark ups time varying and strenghten the redistributive effect of shocks. In their absence, mark-ups are constant and shocks trigger much less redistribution, which occurs as a consequence of variations in relative factor incomes. Consider for instance a positive TFP shock. Under price stickiness, the expansion in the productive capacity of firms does not imply a sudden fall of prices. As market demand does not absorb all the new productive potential at the rigid market price, firms cut worked hours. The fall in labor incomes causes a reduction of RT consumption, while firm margins and profits go up, increasing the welfare of Ricardian agents. Under flexible prices market demand absorbs all the new productive potential, worked hours do not fall and RT consumption grows along with that of Ricardians. The idiosyncratic non-insurable risk faced by Ricardians is limited to the variation in capital returns. This exercise therefore shows that LAMP can have a significant effect on the equity premium only if labor and capital income move in opposite directions, and that is the case only if prices are sticky. Notice that the redistributive effect of shocks is so important, that even if the overall volatility of the economy is larger when prices are flexible, the risk premium is in fact lower.

	σ_y	$\frac{\sigma_{inv}}{\sigma_y}$	$\frac{\sigma_c}{\sigma_y}$	$\frac{\sigma_n}{\sigma_y}$	$\rho_{y,inv}$	$\rho_{y,c}$	$\rho_{y,n}$
US data 1950-2007	1.06	2.88	0.77	1.98	0.7	0.81	0.89
Model							
Benchmark	0.56	2.86	0.61	1.89	0.93	0.89	-0.35
$\chi = 0$	1.11	1.51	0.86	0.97	0.99	0.99	0.29
$X^K = 0.5$	0.89	3.16	0.56	1.26	0.93	0.83	0.13
$\phi = 5$	0.70	2.47	0.7	1.15	0.92	0.93	-0.57
$K = 0$	0.99	1.62	0.91	0.5	0.88	0.97	-0.38
$X = 0$ & $\psi = 0.2$	0.52	2.99	0.62	2.05	0.92	0.85	-0.42

Table 9 - All moments are quarterly. Data: see Appendix B.

Unconditional moments	$E[R_{t+1}^{eq} - R_t^R]$	ER_t^R	σ_{RR}	σ_{Req}	$\rho_{req,c}$	$\rho_{req,n}$
US data 1950-2007	5.1	1.02	2.36	15.02	0.05	-0.19
Model						
Literature Calibration $\psi = 0.4$	2.23	3.04	2.75	15.35	0.35	-0.98
$\chi = 0$	2.39	2.85	2.57	15.22	0.54	-0.62
$X^K = 0.5$	1.66	3.29	2.52	13.23	-0.02	-0.93
$\phi = 5$	3.03	2.72	3.29	18.19	0.72	-0.96
$K = 0$	1.31	3.47	4.27	12	0.87	-0.74
$X = 0$ & $\psi = 0.2$	2.18	3.16	3.1	15.95	0.32	-0.99

Table 10 - All moments are yearly. The standard deviations are 200 times the quarterly model concept. Data: see Appendix B.

4.1.1 Consumption Habits

Eliminating consumption habits from the model raises the equity premium. This is at odds with what usually found in the literature, where consumption habits are considered a useful tool to get an equity premium consistent with the data (Uhlig, 2007). Notice that this obtains because removing habits almost doubles output growth volatility. In addition, the volatility of investment

falls strongly, while that of consumption grows. This is inconsistent with the data, where investment is much more volatile than consumption.

4.1.2 Capital Adjustment Costs

An increase of X^K to 0.5 corresponds to a reduction of real frictions on capital accumulation. As shown in the literature (Boldrin et al (2001), De Paoli et al (2010)), capital adjustment costs are fundamental to produce a relatively high equity premium. We confirm this result. Smaller capital adjustment costs allow Ricardian households to smooth consumption by adjusting the capital stock, which renders their investment in stocks less risky. The equity premium falls from 2.23 to 1.66 when X^K grows from 0.23 to 0.5. Still, LAMP allows to increase the equity premium with respect to the representative agent model. In fact the representative agent model generates an equity premium of 0.78 even when X^K is 0.23. Notice that lower capital adjustment costs turn the output-hours correlation positive and could in principle help to fit macroeconomic data. On the other hand, such effect seems too costly from the point of view of the performance of the model for what concerns financial statistics.

4.1.3 Frisch Elasticity

An increase of ϕ to 5 corresponds to a reduction of Frisch elasticity to 0.21, near to the value assumed in De Paoli et al (2010).¹⁸ The aggregate labour supply schedule is more rigid when ϕ increases. This tends to raise the equity premium, as agents cannot use hours to offset effects of shocks on consumption. On the other hand, a higher ϕ also increases output volatility, suggesting that at least part of the higher equity premium is due to a higher volatility of the overall economy. Moreover, a lower Frisch elasticity worsens the output-hours correlation.

5 Conclusions

We introduce LAMP in an otherwise standard DSGE model with real and nominal rigidities. Our findings are the following. The combination of LAMP and price stickiness is very useful to fit both macro and financial data. This result is driven by income redistribution following shocks. The consumption of financial market participants is much more volatile than aggregate consumption and more correlated with stock returns. This makes investment in firm shares very risky and provides a justification for the high equity premium found in the data. The model is able to account both for the equity premium and for the low correlation of aggregate consumption with equity returns. Further, the strong correlation between dividends and Ricardian households' consumption unambiguously increases precautionary savings and reduces the riskless rate.

We decompose the equity premium produced by the model in two factors. The first one refers to aggregate risk (measured by the correlation between equity returns and aggregate consumption and hours) whereas the second one refers to idiosyncratic non-insurable risk measured by the correlation between firm profits and equity returns, that is, risk determined by income redistribution. We find that aggregate risk always plays a minor role in shaping the risk premium, while redistribution accounts for the major part of it. In contrast with previous contributions, the fundamental nominal rigidity in our model is price stickiness, not wage stickiness (Uhlig (2007), De Graeve et al (2010)).

¹⁸This value is more consistent with micro estimates but it is at odds with macro estimates.

We consider a TFP shock and an investment specific shock. We find that the TFP shock is the main driver of the equity premium, while the investment specific shock is necessary to replicate macroeconomic statistics. LAMP allows to extract a higher equity premium from a less volatile TFP shock. As a consequence, the investment-specific shock can be given more weight and macroeconomic data can be fitted more easily. Indeed, LAMP affects the response of aggregate variables to shocks only marginally, while its major effect concerns redistribution. The better fit of macroeconomic data obtained under LAMP comes from the bigger role played by the investment specific shock in the variance decomposition of output.

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Appendices

Appendix A: Second order approximations to asset returns

In this appendix, we derive the expressions for the riskless rate and the equity premium reported in the main text. Rearranging marginal utility of Ricardian agents' consumption yields

$$(c_t^o)^{-\sigma} c_{t-1}^{X(\sigma-1)} (1 - \theta n_t^\phi)^{1-\sigma} = \lambda_t^o$$

To help in the computation that follows, it is useful to define the auxiliary variable $x_t = 1 - \theta n_t^\phi$ so that the marginal utility of consumption can be rewritten as $\lambda_t^o = (c_t^o)^{-\sigma} c_{t-1}^{X(\sigma-1)} x_t^{1-\sigma}$.

A second order log-approximation¹⁹ of x_t delivers:

$$\widehat{x}_t = -\frac{\theta\bar{n}^\phi}{1-\theta\bar{n}^\phi}\phi\widehat{\hat{n}}_t - \frac{1}{2}\frac{\theta\bar{n}^\phi}{(1-\theta\bar{n}^\phi)^2}\phi^2\widehat{\hat{n}}_t^2$$

Since marginal utility of consumption is multiplicative in the defined variables, its second order log-approximation is equal to the first order one, hence $\widehat{\lambda}_t^o = -\sigma\widehat{c}_t^o + \chi(\sigma-1)\widehat{c}_{t-1} + (1-\sigma)\widehat{x}_t$. So, substituting for \widehat{x}_t we get:

$$\widehat{\lambda}_t^o = -\sigma\widehat{c}_t^o + \chi(\sigma-1)\widehat{c}_{t-1} + (1-\sigma)\left[-\frac{\theta\bar{n}^\phi}{1-\theta\bar{n}^\phi}\phi\widehat{\hat{n}}_t - \frac{1}{2}\frac{\theta\bar{n}^\phi}{(1-\theta\bar{n}^\phi)^2}\phi^2\widehat{\hat{n}}_t^2\right]$$

As a consequence, the second order log-approximation of the stochastic discount factor is:

$$\widehat{sdf}_t^o = \widehat{\lambda}_t^o - \widehat{\lambda}_{t-1}^o = -\sigma\Delta\widehat{c}_t^o + \chi(\sigma-1)\Delta\widehat{c}_{t-1} + (1-\sigma)\left[-\frac{\theta\bar{n}^\phi}{1-\theta\bar{n}^\phi}\phi\Delta\widehat{\hat{n}}_t - \frac{1}{2}\frac{\theta\bar{n}^\phi}{(1-\theta\bar{n}^\phi)^2}\phi^2\Delta\widehat{\hat{n}}_t^2\right]$$

where for any generic variable h , $\Delta h_t = h_t - h_{t-1}$.

De Paoli et al (2010) show that the real rate can be expressed as: $\widehat{r}_t^R = -E_t\widehat{sdf}_{t+1}^o - \frac{1}{2}Var_t\widehat{sdf}_{t+1}^o$. The conditional expectation of the stochastic discount factor is simply:

$$E_t\widehat{sdf}_{t+1}^o = -\sigma E_t\Delta\widehat{c}_{t+1}^o + \chi(\sigma-1)\Delta\widehat{c}_t + (1-\sigma)\left[-\frac{\theta\bar{n}^\phi}{1-\theta\bar{n}^\phi}\phi E_t\Delta\widehat{\hat{n}}_{t+1} - \frac{1}{2}\frac{\theta\bar{n}^\phi}{(1-\theta\bar{n}^\phi)^2}\phi^2 E_t\Delta\widehat{\hat{n}}_{t+1}^2\right]$$

The conditional variance is instead given by:

$$Var_t\widehat{sdf}_{t+1}^o = \sigma^2 Var_t\Delta\widehat{c}_{t+1}^o + \left[(1-\sigma)\frac{\theta\bar{n}^\phi}{1-\theta\bar{n}^\phi}\phi\right]^2 Var_t\Delta\widehat{\hat{n}}_{t+1} + 2\sigma(1-\sigma)\frac{\theta\bar{n}^\phi}{1-\theta\bar{n}^\phi}\phi Cov_t\left(\Delta\widehat{c}_{t+1}^o, \Delta\widehat{\hat{n}}_{t+1}\right)$$

So the real interest rate at time t is:

$$\begin{aligned}\widehat{r}_t^R &= \sigma E_t\Delta\widehat{c}_{t+1}^o - \chi(\sigma-1)\Delta\widehat{c}_t - (1-\sigma)\left[-\frac{\theta\bar{n}^\phi}{1-\theta\bar{n}^\phi}\phi E_t\Delta\widehat{\hat{n}}_{t+1} - \frac{1}{2}\frac{\theta\bar{n}^\phi}{(1-\theta\bar{n}^\phi)^2}\phi^2 E_t\Delta\widehat{\hat{n}}_{t+1}^2\right] \\ &\quad - \frac{1}{2}\sigma^2 Var_t\Delta\widehat{c}_{t+1}^o - \frac{1}{2}\left[(1-\sigma)\frac{\theta\bar{n}^\phi}{1-\theta\bar{n}^\phi}\phi\right]^2 Var_t\Delta\widehat{\hat{n}}_{t+1} - \sigma(1-\sigma)\frac{\theta\bar{n}^\phi}{1-\theta\bar{n}^\phi}\phi Cov_t\left(\Delta\widehat{c}_{t+1}^o, \Delta\widehat{\hat{n}}_{t+1}\right)\end{aligned}$$

Taking the unconditional expectations of the latter expression, using the law of iterated expectations and noting that $E\widehat{\hat{n}}_{t+1}^2 = E\widehat{\hat{n}}_t^2$, we get the average (stochastic steady state) riskless rate:

$$\begin{aligned}E\widehat{r}_t^R &= (\sigma - \chi(\sigma-1))g - \frac{1}{2}\sigma^2 EVar_t\Delta\widehat{c}_{t+1}^o \\ &\quad + \frac{\theta\bar{n}^\phi(\sigma-1)\sigma\phi}{1-\theta\bar{n}^\phi}\left(E Cov_t\left(\Delta\widehat{c}_{t+1}^o, \Delta\widehat{\hat{n}}_{t+1}\right) - \frac{(\sigma-1)}{2\sigma}\frac{\theta\bar{n}^\phi\phi}{1-\theta\bar{n}^\phi}EVar_t\Delta\widehat{\hat{n}}_{t+1}\right)\end{aligned}$$

¹⁹From now on, log-deviations from the deterministic steady state are expressed with a hat.

In the main text we define the conditional (co)variances of any variables h, j evaluated at the stochastic steady state $ECov_t(h_{t+1}, j_{t+1})$ ($EVar_t(h_{t+1})$) as $cov_{h,j}$ (var_h). Notice that up to a second order conditional second moments are constant, hence $Var_t(h_{t+1}) = var_h \forall t$ and $Cov_t(h_{t+1}, j_{t+1}) = cov_{h,j} \forall t$. Rearranging terms we get:

$$E \ln r_t^R = \ln \frac{1}{\beta} + (\sigma - \chi(\sigma - 1))g - \frac{\sigma^2}{2}var_{c^o} \\ + \frac{\theta \bar{n}^\phi (\sigma - 1) \sigma \phi}{1 - \theta \bar{n}^\phi} \left(cov_{c^o, n} - \frac{\theta \bar{n}^\phi (\sigma - 1) \phi}{2\sigma (1 - \theta \bar{n}^\phi)} var_n \right)$$

which is the expression reported in the main text.

The second order approximation of the equity premium can be expressed as

$$rp_t = E_t r_{t+1}^{eq} - r_t^R = \frac{1}{\beta} \left(E_t [\hat{r}_{t+1}^{eq}] - \hat{r}_t^R + \frac{1}{2} Var_t(\hat{r}_{t+1}^{eq}) \right) = -\frac{1}{\beta} Cov_t(\widehat{sdf}_{t+1}^o, \hat{r}_{t+1}^{eq})$$

Since the covariance between equity returns and the stochastic discount factor is $-\sigma Cov_t(\widehat{c}_{t+1}^o, \hat{r}_{t+1}^{eq}) - (1 - \sigma) \phi \frac{\theta \bar{n}^\phi}{1 - \theta \bar{n}^\phi} Cov_t(\hat{n}_{t+1}, \hat{r}_{t+1}^{eq})$, we get:

$$rp_t = \frac{1}{\beta} \left(\sigma Cov_t(\widehat{c}_{t+1}^o, \hat{r}_{t+1}^{eq}) + (1 - \sigma) \phi \frac{\theta \bar{n}^\phi}{1 - \theta \bar{n}^\phi} Cov_t(\hat{n}_{t+1}, \hat{r}_{t+1}^{eq}) \right)$$

Again, making the same assumption we made while deriving the riskless rate and taking unconditional expectations, we can rewrite the above as in the main text:

$$rp = r^{eq} - r^R = \frac{1}{\beta} \left(\sigma cov_{c^o, r^{eq}} - (\sigma - 1) \phi \frac{\theta \bar{n}^\phi}{1 - \theta \bar{n}^\phi} cov_{n, r^{eq}} \right)$$

where $r^{eq} = E r_t^{eq}$ and $r^R = E r_t^R$.

In order to re-express everything in terms of aggregate variables, consider the budget constraint of the representative Ricardian household (eq. 4) and aggregate consumption

$$c_t = (1 - \psi) c_t^o + \psi c_t^{rt} = w_t n_t + d_t$$

Then, take the difference between Ricardian agents' consumption and aggregate consumption, namely

$$c_t^o - c_t = \frac{d_t}{1 - \psi} - d_t$$

Rearranging the equation, one gets

$$c_t^o = c_t + \frac{\psi}{1 - \psi} d_t$$

Finally, we take the loglinear approximation of the above expression, which delivers

$$\widehat{c}_t^o = \frac{\bar{c}}{\bar{c}^o} \widehat{c}_t + \frac{\psi}{1 - \psi} \frac{\bar{d}}{\bar{c}^o} \widehat{d}_t$$

From the latter expression, one can get:

$$\begin{aligned} var_{c^o} &= \left(\frac{\bar{c}}{c^o}\right)^2 var_c + \left(\frac{\psi}{1-\psi}\right)^2 \left(\frac{\bar{d}}{c^o}\right)^2 var_d + 2\left(\frac{\bar{c}}{c^o}\right)\left(\frac{\psi}{1-\psi}\right)\left(\frac{\bar{d}}{c^o}\right) cov_{c,d} \\ cov_{c^o,n} &= \left(\frac{\bar{c}}{c^o}\right) cov_{c,n} + \left(\frac{\psi}{1-\psi}\right)\left(\frac{\bar{d}}{c^o}\right) cov_{n,d} \end{aligned}$$

and:

$$\begin{aligned} rp &= r^{eq} - r^R = \frac{1}{\beta} \left(\sigma cov_{c^o,req} - \phi \frac{\theta \bar{n}^\phi}{1 - \theta \bar{n}^\phi} (\sigma - 1) cov_{n,req} \right) = \\ &= \frac{\sigma}{\beta} \left(\frac{\bar{c}}{c^o} cov_{c,req} + \frac{\psi}{1-\psi} \frac{\bar{d}}{c^o} cov_{d,req} - \phi \frac{\theta \bar{n}^\phi}{1 - \theta \bar{n}^\phi} \frac{(\sigma - 1)}{\sigma} cov_{n,req} \right) \end{aligned}$$

To obtain the decomposition of the equity premium in equation (17) define optimizers relative marginal utility ($z_t = \frac{\lambda_t^o}{\lambda_t}$) and take logs ($z_t = \lambda_t^o - \lambda_t$). The equity premium can be expressed as $rp_t = \frac{1}{\beta} \left(-Cov_t(\hat{z}_{t+1}, \hat{r}_{t+1}^{eq}) - Cov_t(\hat{\lambda}_{t+1}, \hat{r}_{t+1}^{eq}) \right)$, which unconditionally becomes:

$$rp = \frac{1}{\beta} (-cov_{z,req} - cov_{\lambda,req})$$

The latter expression is the one reported in the main text.

Appendix B: Data and SMM Procedure

From the FRED database we took the dataset for aggregate consumption, output, investment and the price index. Consumption is Real Personal Consumption Expenditures, output is Real Gross Domestic Product while the price index is the Implicit Price Deflator. The latter has level 100 in 2005, while the first two are measured in billions of 2005 dollars. For investment we used Private Nonresidential Fixed Investment, which is in nominal terms and we transformed it to real terms dividing the series by the corresponding price index. All series contain annualized de-seasoned quarterly values.

The data for hours were taken from the Bureau of Labour Statistics database. Hours are Total Hours in Manufacturing and are collected at an annual frequency. Data on stock returns and the real riskless rate are taken from Robert Shiller's website and are also collected at annual frequency. As some of the series are quarterly and others yearly, we transformed the quarterly time series to yearly by summing over the quarters of each year and dividing by four, as the quarterly values are annualized at the source. Since the time unit of the model is a quarter, the SMM estimation was run by annualizing properly the model moments. The values reported in the main text were then transformed back to quarterly, where so indicated. In order to stationarize the series, we took the natural logarithm of the growth ratios for all variables apart from the equity return and the riskless rate. For the latter two variables we took the natural logarithm of the gross returns. The same procedure was applied to the simulated variables.

The standard deviations of the two shocks for the constrained estimation were obtained by minimizing $L = g(b)^T W g(b)$,²⁰ where $g(b) = g(\sigma_\eta, \sigma_F) =$

²⁰To minimise L we use the `fmincon` function in MatLab with a interior point algorithm and a tolerance value equal to $1e^{-5}$.

$$\left[\begin{array}{c} \frac{1}{57} \sum_{t=1951}^{2007} \left(\ln \frac{y_t}{y_{t-1}} \right)^2 - E \left(\ln \frac{y(\sigma_\eta, \sigma_F)_t}{y(\sigma_\eta, \sigma_F)_{t-1}} \right)^2 \\ \frac{1}{57} \sum_{t=1951}^{2007} \{ \ln(1 + r_t^{eq}) - \ln(1 + r_t^r) \} - E \{ \ln(1 + r(\sigma_\eta, \sigma_F)_t^{eq}) - \ln(1 + r(\sigma_\eta, \sigma_F)_t^r) \} \end{array} \right] \text{ and } W$$

is a 2x2 identity matrix. Notice that $\ln \frac{y_t}{y_{t-1}}$ was demeaned before the estimation and so $\frac{1}{57} \sum_{t=1951}^{2007} \left(\ln \frac{y_t}{y_{t-1}} \right)^2$

is the variance of the sample. $E \left(\ln \frac{y(\sigma_\eta, \sigma_F)_t}{y(\sigma_\eta, \sigma_F)_{t-1}} \right)^2$ and $E \{ \ln(1 + r(\sigma_\eta, \sigma_F)_t^{eq}) - \ln(1 + r(\sigma_\eta, \sigma_F)_t^r) \}$ can be obtained as theoretical moments since we use a second order approximation or obtained through simulation, in which case they are estimated as $\frac{1}{\tau * 57} \sum_{t=1}^{\tau * 57} \left(\ln \frac{y(\sigma_\eta, \sigma_F)_t}{y(\sigma_\eta, \sigma_F)_{t-1}} \right)^2$ and $\frac{1}{\tau * 57} \sum_{t=1}^{\tau * 57} \{ \ln(1 + r(\sigma_\eta, \sigma_F)_t^{eq}) - \ln(1 + r(\sigma_\eta, \sigma_F)_t^r) \}$ where $\tau * 57$ is the simulation length. The two approaches deliver almost the same results.

In the unconstrained case, $g(b) = g(\sigma_\eta, \sigma_F, \psi) =$

$$\begin{aligned}
& \frac{1}{57} \sum_{t=1951}^{2007} \left(\ln \frac{n_t}{n_{t-1}} \right)^2 - E \left(\ln \frac{n(\sigma_\eta, \sigma_F, \psi)_t}{n(\sigma_\eta, \sigma_F, \psi)_{t-1}} \right)^2 \\
& \frac{1}{57} \sum_{t=1951}^{2007} \ln \frac{n_t}{n_{t-1}} \ln(1 + r_t^{eq}) - E \left(\ln \frac{n(\sigma_\eta, \sigma_F, \psi)_t}{n(\sigma_\eta, \sigma_F, \psi)_{t-1}} \ln(1 + r(\sigma_\eta, \sigma_F, \psi)_t^{eq}) \right) \\
& \frac{1}{57} \sum_{t=1951}^{2007} \ln \frac{n_t}{n_{t-1}} \ln \frac{y_t}{y_{t-1}} - E \left(\ln \frac{n(\sigma_\eta, \sigma_F, \psi)_t}{n(\sigma_\eta, \sigma_F, \psi)_{t-1}} \ln \frac{y(\sigma_\eta, \sigma_F, \psi)_t}{y(\sigma_\eta, \sigma_F, \psi)_{t-1}} \right) \\
& \frac{1}{57} \sum_{t=1951}^{2007} (\ln(1 + r_t^{eq}))^2 - E (\ln(1 + r(\sigma_\eta, \sigma_F, \psi)_t^{eq}))^2 \\
& \frac{1}{57} \sum_{t=1951}^{2007} \ln \frac{c_t}{c_{t-1}} \ln(1 + r_t^{eq}) - E \left(\ln \frac{c(\sigma_\eta, \sigma_F, \psi)_t}{c(\sigma_\eta, \sigma_F, \psi)_{t-1}} \ln(1 + r(\sigma_\eta, \sigma_F, \psi)_t^{eq}) \right) \\
& \frac{1}{57} \sum_{t=1951}^{2007} (\ln(1 + r_t^r))^2 - E (\ln(1 + r(\sigma_\eta, \sigma_F, \psi)_t^r))^2 \\
& \frac{1}{57} \sum_{t=1951}^{2007} \left(\ln \frac{y_t}{y_{t-1}} \right)^2 - E \left(\ln \frac{y(\sigma_\eta, \sigma_F, \psi)_t}{y(\sigma_\eta, \sigma_F, \psi)_{t-1}} \right)^2 \\
& \frac{1}{57} \sum_{t=1951}^{2007} \ln \frac{inv_t}{inv_{t-1}} \ln \frac{y_t}{y_{t-1}} - E \left(\ln \frac{inv(\sigma_\eta, \sigma_F, \psi)_t}{inv(\sigma_\eta, \sigma_F, \psi)_{t-1}} \ln \frac{y(\sigma_\eta, \sigma_F, \psi)_t}{y(\sigma_\eta, \sigma_F, \psi)_{t-1}} \right) \\
& \frac{1}{57} \sum_{t=1951}^{2007} \ln \frac{c_t}{c_{t-1}} \ln \frac{y_t}{y_{t-1}} - E \left(\ln \frac{c(\sigma_\eta, \sigma_F, \psi)_t}{c(\sigma_\eta, \sigma_F, \psi)_{t-1}} \ln \frac{y(\sigma_\eta, \sigma_F, \psi)_t}{y(\sigma_\eta, \sigma_F, \psi)_{t-1}} \right) \\
& \frac{1}{57} \sum_{t=1951}^{2007} \left(\ln \frac{inv_t}{inv_{t-1}} \right)^2 - E \left(\ln \frac{inv(\sigma_\eta, \sigma_F, \psi)_t}{inv(\sigma_\eta, \sigma_F, \psi)_{t-1}} \right)^2 \\
& \frac{1}{57} \sum_{t=1951}^{2007} \left(\ln \frac{c_t}{c_{t-1}} \right)^2 - E \left(\ln \frac{c(\sigma_\eta, \sigma_F, \psi)_t}{c(\sigma_\eta, \sigma_F, \psi)_{t-1}} \right)^2 \\
& \frac{1}{57} \sum_{t=1951}^{2007} \{ \ln(1 + r_t^{eq}) - \ln(1 + r_t^r) \} - E \{ \ln(1 + r(\sigma_\eta, \sigma_F, \psi)_t^{eq}) - \ln(1 + r(\sigma_\eta, \sigma_F, \psi)_t^r) \} \\
& \frac{1}{57} \sum_{t=1951}^{2007} \ln(1 + r_t^r) - E \ln(1 + r(\sigma_\eta, \sigma_F, \psi)_t^r)
\end{aligned}$$

All variables were demeaned before estimation. The weighting matrix is such that a very high loss is associated to deviating from the perfect fit of output volatility and of the equity premium, while other moments were weighted equally. In practice, W is a diagonal matrix, with all diagonal entries equal to one apart from $W(7, 7)$ and $W(12, 12)$ which we set to 10000.

Appendix C: Model Derivation

Ricardian Households

As Ricardian households are intra-group symmetric, we can consider a representative Ricardian households, whose problem is:

$$\begin{aligned} \max E_0 \sum_{t=0}^{\infty} \beta^t U(c_t^o, n_t) &= E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{1-\sigma} \left(\frac{c_t^o}{c_{t-1}^o} \left(1 - \theta \left(\int_0^1 n_{h,t} dh \right)^\phi \right) \right)^{1-\sigma} \\ \text{s.t. } P_t c_t^o + V_t^N B_t^{N,o} + v_t^R P_t B_t^{R,o} + V_t^{eq} S_t^o &\leq \int_0^1 W_{h,t} n_{h,t} dh + B_{t-1}^{N,o} + B_{t-1}^{R,o} P_t + (V_t^{eq} + D_t) S_{t-1}^o \\ S_{-1}, B_{-1}^{R,o}, B_{-1}^{N,o}, c_{-1} &\text{ given} \end{aligned}$$

We adopt the convention of dating state variables at time $t-1$. Notice that we explicitly consider the fact that households supply a continuum of labor types h , at nominal wage rate W_h . The wage rate is set by unions. The Lagrangian is:

$$L = E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \begin{aligned} &\frac{1}{1-\sigma} \left(\frac{c_t^o}{c_{t-1}^o} \left(1 - \theta \left(\int_0^1 n_{h,t} dh \right)^\phi \right) \right)^{1-\sigma} \\ &-\lambda_t \left[c_t^o + \frac{V_t^N}{P_t} B_t^{N,o} + v_t^R B_t^{R,o} + \frac{V_t^{eq}}{P_t} S_t^o - \frac{\int_0^1 W_{h,t} n_{h,t} dh}{P_t} - \frac{B_{t-1}^{N,o}}{P_t} - B_{t-1}^{R,o} - \frac{(V_t^{eq} + D_t)}{P_t} S_{t-1}^o \right] \end{aligned} \right\}$$

The first order conditions are:

$$\begin{aligned} \frac{\partial L}{\partial c_t^o} &= \lambda_t^o - (c_t^o)^{-\sigma} \left(\frac{1 - \theta \left(\int_0^1 n_{h,t} dh \right)^\phi}{c_{t-1}^o} \right)^{1-\sigma} = 0 \\ \frac{\partial L}{\partial S_t^o} &= V_t^{eq} - \beta E_t \left(\frac{\lambda_{t+1}^o}{\lambda_t^o} \frac{V_{t+1}^{eq} + D_{t+1}}{\pi_{t+1}} \right) = 0 \\ \frac{\partial L}{\partial B_t^{R,o}} &= v_t^R - \beta E_t \left(\frac{\lambda_{t+1}^o}{\lambda_t^o} \right) = 0 \\ \frac{\partial L}{\partial B_t^{N,o}} &= V_t^N - \beta E_t \left(\frac{\lambda_{t+1}^o}{\lambda_t^o} \frac{1}{\pi_{t+1}} \right) = 0 \end{aligned}$$

Nominal and indexed bonds are in zero net supply while firms' shares are normalized to one. This implies that the market clearing conditions for the stock, nominal bonds and real bonds markets are respectively:

$$\begin{aligned} S_t^o (1 - \psi) &= 1 \\ B_t^{N,o} (1 - \psi) &= 0 \\ B_t^{R,o} (1 - \psi) &= 0 \end{aligned}$$

Imposing the latter conditions on the budget constraint of Ricardian households gives:

$$c_t^o = \frac{\int_0^1 W_{h,t} n_{h,t} dh}{P_t} + \frac{d_t}{1 - \psi}$$

RT Households

RT households consume their current labor income. Their budget constraint is:

$$c_t^{rt} = \frac{\int_0^1 W_{h,t} n_{h,t} dh}{P_t}$$

Their marginal utility of consumption is defined as:

$$\lambda_t^{rt} = (c_t^{rt})^{-\sigma} \left(\frac{1 - \theta \left(\int_0^1 n_{h,t} dh \right)^\phi}{c_{t-1}^x} \right)^{1-\sigma}$$

Labor Market

The labor market is modeled as in Galí et al (2007) and Colciago (2011). Both papers feature rule of thumb consumers and a representative union.

There is a continuum of differentiated labor types indexed by h on the interval $[0, 1]$. Each household supplies all types of labor, but does not optimize with respect to labor effort. There is one labor union for each labor type h , which sets the wage rate for that particular labor type. Then, households stand ready to supply the amount of labor effort n_h , required by labor packers at the wage w_h set by the union. Notice that both RT consumers and Ricardian households supply all types of labor and for each type of labor they are enrolled in a different union. Since each union is a monopolistic supplier of labor type h , it enjoys market power in the market for labor type h . It is important to underline the fact that each union has market power only in the market for the labor type it supplies, not in the labor market as a whole as the labor market operates under monopolistic competition. Labor packers buy the differentiated labor types, aggregate them using a Dixit-Stiglitz technology and sell "aggregate labor" n to firms.

To gather better intuition about the functioning of the labor market, one can think of it as consisting only of two types of labor: say, farmers and carpenters. Both Ricardian agents and RT consumers work part of the day as carpenters and part of the day as farmers. There are two unions, one setting the wage rate for farmers and one setting the wage rate for carpenters: of course the unions will have to care about both agents and will enjoy market power in their own market. Labor packers can be thought of as intermediaries that help firms combine the two labor types to produce the aggregated labor which firms need to produce consumption goods.

Labor packers operate under perfect competition. The problem of one particular labor packer x is the following:

$$\max w_t n_t(x) - \int_0^1 w_{h,t}(x) n_{h,t}(x) dh \quad s.t. \quad n_t(x) = \left[\int_0^1 n_{h,t}(x)^{\frac{\nu-1}{\nu}} dh \right]^{\frac{\nu}{\nu-1}}$$

where $w_t = \frac{W_t}{P_t}$ and $w_{h,t} = \frac{W_{h,t}}{P_t}$. It can be rewritten as:

$$\max w_t \left[\int_0^1 n_{h,t}(x)^{\frac{\nu-1}{\nu}} dh \right]^{\frac{\nu}{\nu-1}} - \int_0^1 w_{h,t}(x) n_{h,t}(x) dh$$

The first order condition is:

$$\frac{\partial}{\partial n_{h,t}(x)} = w_t \left[\int_0^1 n_{h,t}(x)^{\frac{\nu-1}{\nu}} dh \right]^{\frac{1}{\nu-1}} n_{h,t}(x)^{\frac{-1}{\nu}} - w_{h,t}(x) = 0$$

which can be rewritten as:

$$n_{h,t}(x) = \left(\frac{w_{h,t}}{w_t} \right)^{-\nu} n_t(x)$$

Assuming that labor packers have a mass of 1, the "aggregate labor" market clearing condition implies that $\int_0^1 n(x) dx = n^d$, where n^d is the aggregate labor demand on the part of firms. The equilibrium condition for the h labor type market is $\int_0^1 n_h(x) dx = n_h \forall h$, where n_h is the total supply of labor type h. Since packers are symmetric, we have that for each packer $n(x) = n^d$ and $n_h(x) = n_h$. Hence the first order condition can be rewritten as:

$$n_{h,t} = \left(\frac{w_{h,t}}{w_t} \right)^{-\nu} n_t^d$$

The equation is the demand for labor type h considered by union h.

Union for labor type h solves the following problem:

$$\begin{aligned} \max E_0 \sum_{t=0}^{\infty} \beta^t & [(1-\psi) U(c_t^o, n_t) + \psi U(c_t^{rt}, n_t)] \\ \text{s.t. } c_t^o &= \int_0^1 w_{h,t} n_{h,t} dh + \frac{d_t}{1-\psi} - \frac{X}{2} \int_0^1 \left(\frac{w_{h,t} \pi_t}{w_{h,t-1}} - 1 \right)^2 n_t^d dh \\ c_t^{rt} &= \int_0^1 w_{h,t} n_{h,t} dh - \frac{X}{2} \int_0^1 \left(\frac{w_{h,t} \pi_t}{w_{h,t-1}} - 1 \right)^2 n_t^d dh \\ n_{h,t} &= \left(\frac{w_{h,t}}{w_t} \right)^{-\nu} n_t^d \\ n_t &= \int_0^1 n_{h,t} dh \end{aligned}$$

where I already imposed intra-group symmetry among Ricardian and RT consumers. n is total worked hours given by the sum of the effort exerted in each labor type market. The problem can be rewritten as:

$$\begin{aligned} \max E_0 \sum_{t=0}^{\infty} \beta^t & \left[(1-\psi) U \left(c_t^o, \int_0^1 \left(\frac{w_{h,t}}{w_t} \right)^{-\nu} n_t^d dh \right) + \psi U \left(c_t^{rt}, \int_0^1 \left(\frac{w_{h,t}}{w_t} \right)^{-\nu} n_t^d dh \right) \right] \\ \text{s.t. } c_t^o &= \int_0^1 w_{h,t} \left(\frac{w_{h,t}}{w_t} \right)^{-\nu} n_t^d dh + \frac{d_t}{1-\psi} - \frac{X}{2} \int_0^1 \left(\frac{w_{h,t} \pi_t}{w_{h,t-1}} - 1 \right)^2 n_t^d dh \\ c_t^{rt} &= \int_0^1 w_{h,t} \left(\frac{w_{h,t}}{w_t} \right)^{-\nu} n_t^d dh - \frac{X}{2} \int_0^1 \left(\frac{w_{h,t} \pi_t}{w_{h,t-1}} - 1 \right)^2 n_t^d dh \end{aligned}$$

The Lagrangian is:

$$L = E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \begin{array}{l} \left[(1-\psi) U \left(c_t^o, \int_0^1 \left(\frac{w_{h,t}}{w_t} \right)^{-\nu} n_t^d dh \right) + \psi U \left(c_t^{rt}, \int_0^1 \left(\frac{w_{h,t}}{w_t} \right)^{-\nu} n_t^d dh \right) \right] \\ - (1-\psi) \lambda_t^o \left[c_t^o - \int_0^1 w_{h,t} \left(\frac{w_{h,t}}{w_t} \right)^{-\nu} n_t^d dh - \frac{d_t}{1-\psi} + \frac{X}{2} \int_0^1 \left(\frac{w_{h,t} \pi_t}{w_{h,t-1}} - 1 \right)^2 n_t^d dh \right] \\ - \psi \lambda_t^{rt} \left[c_t^{rt} - \int_0^1 w_{h,t} \left(\frac{w_{h,t}}{w_t} \right)^{-\nu} n_t^d dh + \frac{X}{2} \int_0^1 \left(\frac{w_{h,t} \pi_t}{w_{h,t-1}} - 1 \right)^2 n_t^d dh \right] \end{array} \right\}$$

The first order condition with respect to w_h is:

$$\begin{aligned} & - \left[\psi \frac{\partial U(c_t^{rt}, n_t)}{\partial n_t} + (1-\psi) \frac{\partial U(c_t^o, n_t)}{\partial n_t} \right] \nu \left(\frac{w_{h,t}}{w_t} \right)^{-\nu-1} \frac{n_t^d}{w_t} \\ & + [(1-\psi) \lambda_t^o + \psi \lambda_t^{rt}] (1-\nu) \left(\frac{w_{h,t}}{w_t} \right)^{-\nu} n_t^d \\ & - [(1-\psi) \lambda_t^o + \psi \lambda_t^{rt}] X n_t^d \left(\frac{w_{h,t} \pi_t}{w_{h,t-1}} - 1 \right) \frac{\pi_t}{w_{h,t-1}} \\ & + \beta E_t \left[((1-\psi) \lambda_{t+1}^o + \psi \lambda_{t+1}^{rt}) X n_{t+1}^d \left(\frac{w_{h,t+1} \pi_{t+1}}{w_{h,t}} - 1 \right) \frac{w_{h,t+1} \pi_{t+1}}{w_{h,t}^2} \right] = 0 \end{aligned}$$

Under the Rotemberg specification, all unions set the same wage and each labor type h is paid the same wage, so $w_{h,t} = w_t \forall h$ and $n_t = n_t^d$. Hence, the first order condition can be rewritten as follows:

$$\begin{aligned} & - \left[\psi \frac{\partial U(c_t^{rt}, n_t)}{\partial n_t} + (1-\psi) \frac{\partial U(c_t^o, n_t)}{\partial n_t} \right] \nu \frac{n_t}{w_t} \\ & + [(1-\psi) \lambda_t^o + \psi \lambda_t^{rt}] (1-\nu) n_t \\ & - [(1-\psi) \lambda_t^o + \psi \lambda_t^{rt}] X n_t \left(\frac{w_t \pi_t}{w_{t-1}} - 1 \right) \frac{\pi_t}{w_{t-1}} \\ & + \beta E_t \left[((1-\psi) \lambda_{t+1}^o + \psi \lambda_{t+1}^{rt}) X n_{t+1} \left(\frac{w_{t+1} \pi_{t+1}}{w_t} - 1 \right) \frac{w_{t+1} \pi_{t+1}}{w_t^2} \right] = 0 \end{aligned}$$

Multiplying all terms by $\frac{w_t}{n_t}$ one gets:

$$\begin{aligned} & - \left[\psi \frac{\partial U(c_t^{rt}, n_t)}{\partial n_t} + (1-\psi) \frac{\partial U(c_t^o, n_t)}{\partial n_t} \right] \nu \\ & + [(1-\psi) \lambda_t^o + \psi \lambda_t^{rt}] (1-\nu) w_t \\ & - [(1-\psi) \lambda_t^o + \psi \lambda_t^{rt}] X \left(\frac{w_t \pi_t}{w_{t-1}} - 1 \right) \frac{w_t \pi_t}{w_{t-1}} \\ & + \beta E_t \left[((1-\psi) \lambda_{t+1}^o + \psi \lambda_{t+1}^{rt}) X \frac{n_{t+1}}{n_t} \left(\frac{w_{t+1} \pi_{t+1}}{w_t} - 1 \right) \frac{w_{t+1} \pi_{t+1}}{w_t} \right] = 0 \end{aligned}$$

Then, divide all terms by $(1 - \psi) \lambda_t^o + \psi \lambda_t^{rt}$:

$$\begin{aligned} & - \left[\psi \frac{\partial U(c_t^{rt}, n_t)}{\partial n_t} + (1 - \psi) \frac{\partial U(c_t^o, n_t)}{\partial n_t} \right] \\ & \frac{\nu}{(1 - \psi) \lambda_t^o + \psi \lambda_t^{rt} + (1 - \nu) w_t} \\ & - X \left(\frac{w_t \pi_t}{w_{t-1}} - 1 \right) \frac{w_t \pi_t}{w_{t-1}} \\ & + \beta E_t \left[\frac{(1 - \psi) \lambda_{t+1}^o + \psi \lambda_{t+1}^{rt}}{(1 - \psi) \lambda_t^o + \psi \lambda_t^{rt}} X \frac{n_{t+1}}{n_t} \left(\frac{w_{t+1} \pi_{t+1}}{w_t} - 1 \right) \frac{w_{t+1} \pi_{t+1}}{w_t} \right] = 0 \end{aligned}$$

Dividing all terms by ν and rearranging, one gets:

$$\begin{aligned} & - \left[\psi \frac{\partial U(c_t^{rt}, n_t)}{\partial n_t} + (1 - \psi) \frac{\partial U(c_t^o, n_t)}{\partial n_t} \right] \\ & \frac{1}{(1 - \psi) \lambda_t^o + \psi \lambda_t^{rt}} = \\ & \frac{\nu - 1}{\nu} w_t + \frac{X}{\nu} \left(\frac{w_t \pi_t}{w_{t-1}} - 1 \right) \frac{w_t \pi_t}{w_{t-1}} \\ & - \beta \frac{X}{\nu} E_t \left[\frac{(1 - \psi) \lambda_{t+1}^o + \psi \lambda_{t+1}^{rt}}{(1 - \psi) \lambda_t^o + \psi \lambda_t^{rt}} \frac{n_{t+1}}{n_t} \left(\frac{w_{t+1} \pi_{t+1}}{w_t} - 1 \right) \frac{w_{t+1} \pi_{t+1}}{w_t} \right] \end{aligned}$$

Goods Market

There is a continuum of differentiated goods indexed by z in the interval $(0, 1)$. Each good is produced by one intermediate goods firm under monopolistic competition. Final good firms buy the differentiated goods and aggregate them to produce the final good which is then either consumed by households or used as an investment good by intermediate firms.

The problem of final good firm x is:

$$\max P_t y_t(x) - \int_0^1 P_{Z,t} y_{Z,t}(x) dz \quad s.t. \quad y_t(x) = \left[\int_0^1 y_{Z,t}(x)^{\frac{\mu-1}{\mu}} dz \right]^{\frac{\mu}{\mu-1}}$$

Substituting the production function in the objective function one obtains:

$$\max P_t \left[\int_0^1 y_{Z,t}(x)^{\frac{\mu-1}{\mu}} dz \right]^{\frac{\mu}{\mu-1}} - \int_0^1 P_{Z,t} y_{Z,t}(x) dz$$

The first order condition is:

$$\frac{\partial}{\partial y_{Z,t}(x)} = P_t \left[\int_0^1 y_{Z,t}(x)^{\frac{\mu-1}{\mu}} dz \right]^{\frac{1}{\mu-1}} y_{Z,t}(x)^{\frac{-1}{\mu}} - P_{Z,t}(x) = 0$$

which can be rewritten as:

$$y_{Z,t}(x) = \left(\frac{P_{Z,t}}{P_t} \right)^{-\mu} y_t(x)$$

Assuming that final good firms have a mass of 1, the final good market clearing condition implies that $\int_0^1 y(x) dx = y = c + i$, where y is the final good aggregate demand, which equals consumption plus investment. The equilibrium condition for the z good market is $\int_0^1 y_Z(x) dx = y_Z \forall Z$. Since final good producers are symmetric, we have that for each final good firm $y(x) = y$ and $y_Z(x) = y_Z$. Hence we can write:

$$y_{Z,t} = \left(\frac{P_{Z,t}}{P_t} \right)^{-\mu} y_t$$

The problem of the intermediate firm producing good z is:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t \lambda_t^o [d_{Z,t} - \frac{K}{2} \left(\frac{P_{Z,t}}{P_{Z,t-1}} - 1 \right)^2 y_t]$$

$$s.t. \quad d_{Z,t} \leq \frac{P_{Z,t}}{P_t} y_{Z,t} - w_t n_{Z,t}^d - i_{Z,t}$$

$$y_{Z,t} \leq A_t (n_{Z,t}^d)^\alpha k_{Z,t-1}^{1-\alpha} - e^g f c$$

$$y_{Z,t} = \left(\frac{P_{Z,t}}{P_t} \right)^{-\mu} y_t$$

$$k_{Z,t} \leq (1 - \delta) k_{Z,t-1} + F_t \omega(i_{Z,t}, k_{Z,t-1}) k_{Z,t-1}$$

$$k_{Z,-1}, P_{Z,-1} \text{ given}$$

The Lagrangian is:

$$L = E_0 \sum_{t=0}^{\infty} \beta^t \lambda_t^o \left\{ \begin{array}{l} \frac{P_{Z,t}}{P_t} \left(\frac{P_{Z,t}}{P_t} \right)^{-\mu} y_t - w_t n_{Z,t}^d - i_{Z,t} - \frac{K}{2} \left(\frac{P_{Z,t}}{P_{Z,t-1}} - 1 \right)^2 y_t \\ - m c_{Z,t} \left(\left(\frac{P_{Z,t}}{P_t} \right)^{-\mu} y_t - A_t (n_{Z,t}^d)^\alpha k_{Z,t-1}^{1-\alpha} + e^g f c \right) \\ - q_{Z,t} (k_{Z,t} - (1 - \delta) k_{Z,t-1} - F_t \omega(i_{Z,t}, k_{Z,t-1}) k_{Z,t-1}) \end{array} \right\}$$

The first order conditions are:

$$\frac{\partial L}{\partial n_{Z,t}^d} = -w_t + m c_{Z,t} \alpha A_t \left(\frac{n_{Z,t}^d}{k_{Z,t-1}} \right)^{\alpha-1} = 0$$

$$\frac{\partial L}{\partial i_{Z,t}} = q_{Z,t} - \frac{1}{F_t \left(a_1 \left(\frac{i_{Z,t}}{k_{Z,t-1}} \right)^{-\frac{1}{\alpha K}} \right)} = 0$$

$$\frac{\partial L}{\partial k_{Z,t}} = q_{Z,t} - E_t \left\{ \beta \frac{\lambda_{t+1}^o}{\lambda_t^o} \left(\begin{array}{l} m c_{Z,t+1} A_{t+1} (1 - \alpha) n_{Z,t+1}^\alpha k_{Z,t}^{-\alpha} \\ + q_{Z,t+1} [1 - \delta + F_{t+1} \left(\left(\frac{1}{1 - \frac{1}{\alpha K}} - 1 \right) a_1 \left(\frac{i_{Z,t}}{k_{Z,t}} \right)^{1 - \frac{1}{\alpha K}} + a_2 \right)] \end{array} \right) \right\} = 0$$

$$\begin{aligned} \frac{\partial L}{\partial P_{Z,t}} &= \frac{(1-\mu)}{\mu} \left(\frac{P_{Z,t}}{P_t} \right)^{-\mu-1} - \frac{K}{\mu} \left(\frac{P_{Z,t}}{P_{Z,t-1}} - 1 \right) \frac{P_t}{P_{Z,t-1}} \\ &+ \beta E_t \left[\frac{\lambda_{t+1}^o}{\lambda_t^o} \frac{K}{\mu} \left(\frac{P_{Z,t+1}}{P_{Z,t}} - 1 \right) \frac{P_{Z,t+1} P_t y_{t+1}}{P_{Z,t}^2 y_t} \right] + mc_{Z,t} \left(\frac{P_{Z,t}}{P_t} \right)^{-\mu-1} = 0 \end{aligned}$$

Under the Rotemberg specification, all intermediate firms set the same price, so $P_{Z,t} = P_t \forall Z$ and $y_{Z,t} = y_t$. Hence, the first order conditions can be rewritten as follows:

$$w_t = mc_t A_t \alpha n_t^{\alpha-1} k_{t-1}^{1-\alpha}$$

$$q_t = \frac{1}{F_t \left(a_1 \left(\frac{i_t}{k_{t-1}} \right)^{-\frac{1}{\alpha K}} \right)}$$

$$q_t = E_t \left\{ \beta \frac{\lambda_{t+1}^o}{\lambda_t^o} \left(\begin{aligned} &mc_{t+1} A_{t+1} (1-\alpha) n_{t+1}^\alpha k_t^{-\alpha} \\ &+ q_{t+1} [1 - \delta + F_{t+1} \left(\left(\frac{1}{1-\frac{1}{\alpha K}} - 1 \right) a_1 \left(\frac{i_t}{k_t} \right)^{1-\frac{1}{\alpha K}} + a_2 \right)] \end{aligned} \right) \right\}$$

$$mc_t = \frac{\mu-1}{\mu} + \frac{K}{\mu_t} (\pi_t - 1) \pi_t - \beta E_t \left[\frac{\lambda_{t+1}^o}{\lambda_t^o} \frac{K}{\mu} (\pi_{t+1} - 1) \pi_{t+1} \frac{y_{t+1}}{y_t} \right]$$

Limited Asset Market Participation and the Optimal Rate of Inflation

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Abstract

In the workhorse DSGE model, the optimal steady state inflation rate is near to zero or slightly negative and inflation is almost completely stabilized along the business cycle (Schmitt-Grohé and Uribe (2011)). We reconsider the issue, allowing for agent heterogeneity in the access to the market for interest bearing assets. We show that the optimal inflation rate rises in the share of constrained individuals and that this effect is robust to the introduction of redistributive transfers. The optimal response to government consumption shocks is also affected. Rather than stabilising inflation and letting public debt jump on impact, the Ramsey planner frontloads fiscal adjustment and increases tax rates.

Jel codes: E52, E58, J51, E24.

Keywords: trend inflation, monetary and fiscal policy, Ramsey plan, Limited Asset Market Participation.

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1 Introduction

In the workhorse DSGE model the optimal steady state inflation rate is near to zero or slightly negative and inflation is almost completely stabilized along the business cycle (Schmitt-Grohé and Uribe, 2011). The result follows from the interaction of monetary transaction costs, which call for a zero nominal interest rate and a negative growth rate of prices (the Friedman rule), and price adjustment costs, which push the optimal inflation rate to zero. Phelps (1973) conjectured that monetary financing could be used to alleviate the burden of distortionary taxation, when an exogenous amount of public spending has to be financed and lump sum taxation is not available. Schmitt-Grohé and Uribe (2011), in their survey of the literature, show that the optimality of price stability is robust to the Phelps' effect as well as to other frictions such as downward wage rigidity, hedonic prices, incompleteness of the tax system and the zero lower bound on the nominal interest rate. Di Bartolomeo et al (2014) question the standard result as based on an unrealistic calibration of the composition of public spending. In fact it is common practice in the literature to assume that most part of public expenditures consist of public consumption, typically set to the 20% of GDP, and to abstract from public transfers. When transfers are calibrated to values consistent with the ones prevailing in OECD countries (12% to 20% of GDP), the optimal inflation rate ranges between 2% and 12%.

Another popular argument in favour of price stability is the asymmetric incidence of the inflation tax when wealth is unevenly distributed and portfolio composition of poorer households is skewed towards a larger share of money holdings, so that the inflation tax burden would disproportionately fall on the poor. (Erosa and Ventura (2002); Albanesi (2007); Boel and Camera (2009); Schmitt-Grohé and Uribe (2011)).

In this paper we re-examine the issue allowing for Limited Asset Market Participation (LAMP henceforth), in the form of a distinction between interest bearing assets holders (unconstrained agents) and agents who only own money (constrained agents).¹ This approach allows us to verify how inequality concerns (and the uneven effect of the inflation tax on the poorer part of the population) affect the optimal rate of inflation in a straightforward and simple way. The issue is rather important as the DSGE literature based on the representative agent assumption simply ignores inequality concerns which can play a fundamental role in shaping social choices.

Heterogeneity in the access to the market for interest bearing assets is a salient feature of the data. While the majority of US families² (92.5%) hold transaction accounts (which include checking, savings, money market deposit accounts and money market mutual funds), only a small minority hold other financial assets, such as stocks, bonds, investment funds and other managed assets (which are all held by less than the 20% of families). The major long term saving vehicle for US households are retirement accounts, which are held only by the 50.4% of families.

¹An example of this approach is found in Coenen et al (2008) .

²These statistics refer to the 2010 Survey of Consumer Finances.

Percentage of Families Holding Asset	
Transaction Accounts	92.5
Certificate of Deposits	12.2
Savings Bonds	12.0
Bonds	1.6
Stocks	15.1
Pooled Investment Funds	8.7
Retirement Accounts	50.4
Cash Value Life Insurance	19.7
Other Managed Assets	5.7
Other	8.0
Any Financial Asset	94.0

Table 1: Data taken from the Federal Reserve Bulletin, June 2012, Vol 98, No 2. 2010 Survey.

Excluding such important differences in wealth holdings from macroeconomic models implies that the distributional effects of policies and shocks are also ignored.

Our analysis unfolds in 3 steps. The first step is the identification of the policymaker's incentive to use inflation as a redistributive tool, highlighting the efficiency-equity trade off. To this end we focus on a very simple model where goods are produced by monopolistic firms, individuals inelastically supply labor, public consumption is nil and the subjective discount factor is one, so that the Friedman rule should call for zero inflation. In this model, income inequality is determined by profits entirely earned by assets holders, and we allow the planner to print money to finance lump-sum transfers to non-asset holders. We obtain analytical results showing that inequality in individual wealth holdings unambiguously induces the policymaker to raise inflation, thus highlighting the importance of the redistribution motive in shaping optimal policies.

The second step in our analysis is to allow for an endogenous labor supply, and to assume that the planner can offset monopolistic distortions through inflation-financed production subsidies. We find that it is indeed optimal to levy an inflation tax which increases in the share of households whose wealth is entirely composed of money holdings. This latter result suggests that LAMP should induce the planner to shift the optimal financing mix towards inflation in the more realistic framework where distortionary taxes are needed to finance public expenditures and monopolistic distortions cannot be removed through production subsidies.

To verify this latter conjecture, in the third step of our analysis we compute the Ramsey solution for the N-K DSGE model in Di Bartolomeo et al (2014), that we extend to account for LAMP. This implies that the planner's problem is the identification of the optimal financing mix (inflation and labor income tax) for a given level and composition of public expenditures (between consumption and transfers). This adds to Schmitt-Grohé and Uribe (2004a) and Di Bartolomeo et al (2014) because we focus on the planner's concern for redistribution as a determinant of inflation. We find that consumer heterogeneity tends to increase the optimal steady state inflation rate. In contrast with received wisdom, the fundamental reason underlying this result is that expected inflation shifts the fiscal burden towards asset holders. Inflation is a tax on money balances and consumption³ and asset holders consume more and hold more money.⁴ The difference in the consumption of the two agents groups depends on positive profits, and inflation can be seen as an indirect tax on profits.

³A tax on money balances implies, *cet. par.*, higher transaction costs and lower consumption.

⁴The transaction technology implies a positive relationship between consumption and money balances.

Since unconstrained agents are the only owners of firms, they will end up paying in taxes a higher share of their earnings. The lower labor tax will raise the overall labor supply and mainly benefit non asset holders. As the Ramsey planner values redistribution, this implies higher steady state inflation rates relative to a representative agent framework. The optimal inflation rate invariably rises as the share of constrained agents grow. In the presence of public transfers and a share of constrained agents that matches the wealth Gini index for the US, the optimal inflation rate is 4.36%. This is true even though transfers only accrue to constrained agents. If transfers are equally shared among agents, the optimal inflation rate is even higher.

Finally, we analyze the business cycle implications of heterogeneity and obtain the optimal response of policy to a government consumption shock. The optimal financing mix of innovations in public consumption is also strongly affected by the degree of agent heterogeneity. We find that, instead of stabilising inflation and letting public debt jump on impact as is the case under the representative agent model, under agent heterogeneity it is optimal to adjust tax rates. In particular, following a positive government spending shock, the nominal interest rate is cut, inflation rises and the labor tax rate is increased. Public debt retains the unit root feature, but its response is much slower.

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 describes the rational expectations equilibrium and defines the Ramsey optimal policy. In section 4 we obtain the steady state results. Section 5 describes the optimal response to government consumption shocks and section 6 concludes.

2 The model

We consider a simple infinite-horizon production economy populated by a continuum of households i , $i \in [0; 1]$. Monopolistic competition and nominal rigidities characterize product markets. The labor market is competitive. A demand for money is motivated by assuming that money facilitates transactions. Consumption purchases are subject to a transaction cost⁵

$$s\left(\frac{P_{t,i}c_{t,i}}{M_{t,i}}\right), \quad s'\left(\frac{P_{t,i}c_{t,i}}{M_{t,i}}\right) > 0 \text{ for } \frac{P_{t,i}c_{t,i}}{M_{t,i}} > v_i^* \quad (1)$$

where $\frac{P_{t,i}c_{t,i}}{M_{t,i}}$ is the ratio of nominal household's expenditures to money balances and i indexes a generic household. The features of $s\left(\frac{P_{t,i}c_{t,i}}{M_{t,i}}\right)$ are such that a satiation level of money balances ($v^* > 0$) exists where the transaction cost vanishes and, simultaneously, a finite demand for money is associated to a zero nominal interest rate. Following Schmitt-Grohé, S. and M. Uribe (2004a) the transaction cost is parameterized as

$$s\left(\frac{P_{t,i}c_{t,i}}{M_{t,i}}\right) = A \frac{P_{t,i}c_{t,i}}{M_{t,i}} + \frac{B}{\frac{P_{t,i}c_{t,i}}{M_{t,i}}} - 2\sqrt{AB} \quad (2)$$

The government finances an exogenous stream of expenditures⁶ by levying distortionary labor income taxes and by printing money. Optimal policy is set according to a Ramsey plan.

⁵See Sims, C.A. (1994), Schmitt-Grohé and Uribe (2004a), Guerron-Quintana, P.A. (2009).

⁶In some versions of the model we consider endogenous public transfers.

2.1 Households

Households are distributed over the unit interval. A mass $\theta \in [0, 1]$ of agents (constrained agents) indexed by c , cannot participate in the market for interest bearing assets and does not own firms, while a mass $1 - \theta$ of agents (unconstrained agents, henceforth), indexed by u behaves according to the standard model and can buy and sell bonds and own firms. Constrained agents, on the other hand, do hold money balances in order to exploit the transaction technology. All households share the same KPR utility function

$$U = E_0 \sum_{t=0}^{\infty} \beta^t u(c_t^i, l_t^i); \quad u(c_t^i, l_t^i) = \frac{(c_t^i)^{1-\sigma_c}}{1-\sigma_c} e^{\frac{(1-\sigma_c)\eta}{1-\gamma}(1-l_t^i)^{1-\gamma}} \quad (3)$$

where $\beta \in (0, 1)$ is the intertemporal discount rate, l_t^i denotes the individual labor supply, $c_t^i = \left(\int_0^1 c_t^i(j)^\rho dj\right)^{\frac{1}{\rho}}$ is a consumption bundle based on standard Dixit-Stiglitz preferences. Demand for good j therefore is

$$c_t(j) = c_t \left(\frac{p_t(j)}{P_t}\right)^{\frac{1}{\rho-1}} \quad (4)$$

where $P_t = \left(\int_0^1 p_t(i)^{\frac{\rho}{\rho-1}} di\right)^{\frac{\rho-1}{\rho}}$ defines the consumption price index. We assume $u(c_t^i, l_t^i)$ to be strictly increasing, concave ($\sigma_c, \gamma \geq 0$) in consumption and leisure and twice-continuously differentiable. 3 collapses to the standard log-utility separable framework for $\sigma_c = 1$.⁷

2.1.1 Unconstrained consumers

Unconstrained households maximize 3 subject to the flow budget constraint

$$c_t^u \left(1 + s\left(\frac{P_t c_t^u}{M_t^u}\right)\right) + \frac{M_t^u}{P_t} + \frac{B_t^u}{P_t} = (1 - \tau_t) w_t l_t^u + \frac{M_{t-1}^u}{P_t} + \frac{\Pi_t^u}{P_t} + \frac{R_{t-1} B_{t-1}^u}{P_t} + l_t^u \quad (5)$$

and under the constraints

$$c_t^u \geq 0, M_t^u \geq 0, l_t^u \in [0, 1]$$

w_t is the real wage; τ_t is the labor income tax rate; t_t^u denotes real fiscal transfers; Π_t are firms profits; R_t is the gross nominal interest rate, B_t^u is a nominally riskless bond that pays one unit of currency in period $t+1$. M_t^u defines nominal money holdings. Given the functional form of the utility function and the functional form of the transaction technology⁸, the non-negativity constraints on consumption, leisure and money balances are always non-binding and we can ignore them. Our calibration will also assure that hours are always positive. Finally, we impose on unconstrained households the standard no-Ponzi game condition on the accumulation of bonds⁹:

$$\lim_{T \rightarrow \infty} E_t \beta^{T-t} B_T^u \geq 0 \quad (6)$$

⁷For $\sigma_c = 1$, the utility function becomes $u(c_t^i, l_t^i) = \ln c_t^i + \frac{\eta}{1-\gamma}(1-l_t^i)^{1-\gamma}$. For $\gamma = 1$ preferences are logarithmic also in leisure.

⁸The KPR utility function goes to $-\infty$ as consumption approaches zero. It is also easy to see that the limit of transaction costs for money balances that approach zero is infinite. Leisure will also be non-negative as $(1-l_t)^{1-\gamma}$ is not defined for $l_t \leq 0$.

⁹Given that the household does not want to "die" with positive wealth, the no Ponzi game condition will be binding.

for all t .

The first-order conditions of the unconstrained household's maximization problem are:¹⁰

$$\frac{\partial}{\partial c_t^u} = 0 : \lambda_t^u = \frac{u_c(c_t^u, l_t^u)}{1 + s\left(\frac{c_t^u}{m_t^u}\right) + \frac{c_t^u}{m_t^u} s'\left(\frac{c_t^u}{m_t^u}\right)} \quad (7)$$

$$\frac{\partial}{\partial B_t^u} = 0 : \lambda_t^u = \beta E_t \left(\frac{\lambda_{t+1}^u R_t}{\pi_{t+1}} \right) \quad (8)$$

$$\frac{\partial}{\partial l_t^u} = 0 : w_t = -\frac{u_l^u(c_t^u, l_t^u)}{(1 - \tau_t) \lambda_t^u} \quad (9)$$

$$\frac{\partial}{\partial M_t^u} = 0 : \frac{R_t - 1}{R_t} = s'\left(\frac{c_t^u}{m_t^u}\right) \left(\frac{c_t^u}{m_t^u}\right)^2 \quad (10)$$

where $m_t^u = \frac{M_t^u}{P_t}$. As in Schmitt-Grohé and Uribe (2004a) condition (7) states that the transaction cost introduces a wedge between the marginal utility of consumption, $u_c(c_t^u, l_t^u)$, and the marginal utility of wealth, λ_t^u , that vanishes only if $\frac{c_t^u}{m_t^u} = v^*$. Equation (8) is a standard Euler condition where $\pi_{t+1} = P_{t+1}/P_t$ denotes the gross inflation rate. Equation (9) defines the individual labor supply condition. Finally, equation (10) implicitly defines the money demand function. Notice that the nominal interest rate must be non-negative, i.e. $R_t \geq 1, \forall t$.

2.1.2 Constrained consumers

Constrained households maximize (3) subject to the flow budget constraint¹¹

$$c_{t,i}^c \left(1 + s\left(\frac{P_t c_t^c}{M_t^c}\right) \right) + \frac{M_t^c}{P_t} = (1 - \tau_t) w_t l_{t,i}^c + \frac{M_{t-1}^c}{P_t} + t_i^c. \quad (11)$$

The first-order conditions of the constrained household's maximization problem are:

$$\frac{\partial}{\partial c_t^c} = 0 : \lambda_t^c = \frac{u_c(c_t^c, l_t^c)}{1 + s\left(\frac{c_t^c}{m_t^c}\right) + \frac{c_t^c}{m_t^c} s'\left(\frac{c_t^c}{m_t^c}\right)} \quad (12)$$

$$\frac{\partial}{\partial l_t^c} = 0 : w_t = -\frac{u_l(c_t^c, l_t^c)}{(1 - \tau_t) \lambda_t^c} \quad (13)$$

$$\frac{\partial}{\partial M_t^c} = 0 : 1 - E_t \left[\frac{\beta}{\pi_{t+1}} \frac{\lambda_{t+1}^c}{\lambda_t^c} \right] = s'\left(\frac{c_t^c}{m_t^c}\right) \left(\frac{c_t^c}{m_t^c}\right)^2 \quad (14)$$

Equation 14 defines the money demand on the part of constrained households. In particular, the consumption to money ratio of constrained households is a negative function of expected inflation and a positive function of the expected increase in the marginal utility of wealth.¹²

¹⁰When solving its optimization problem, the household takes as given goods and bond prices.

¹¹For the reasons discussed above the constraints $c_t^c \geq 0, M_t^c \geq 0, l_t^c \in [0, 1]$ are non binding.

¹²Note that only in steady state money demand functions (14) and (10) are identical, because in the case $\frac{\lambda_{t+1}^c}{\lambda_t^c} = \frac{\lambda_{t+1}^u}{\lambda_t^u} = 1$ and $R_t = \frac{\pi_{t+1}}{\beta}$.

2.2 Firms' pricing decisions

The j -th firm produces a differentiated good using a linear technology in labor:

$$y_t(j) = l_t(j) \quad (15)$$

We assume a sticky price specification based on a Rotemberg quadratic cost of nominal price adjustment:

$$\frac{\xi_p}{2} y_t (\pi_t - 1)^2 \quad (16)$$

where $\xi_p > 0$ is a measure of price stickiness. In line with Ascari et al (2011), we assume that the re-optimization cost is proportional to output.

In a symmetrical equilibrium the price adjustment rule satisfies:

$$\frac{(\rho - mc_t)}{1 - \rho} + \xi_p \pi_t (\pi_t - 1) = \beta E_t \left[\frac{y_{t+1} \lambda_{t+1}^u}{y_t \lambda_t^u} \xi_p [\pi_{t+1} (\pi_{t+1} - 1)] \right] \quad (17)$$

where

$$mc_t = w_t \quad (18)$$

From (4) it would be straightforward to show that $\frac{1}{\rho} = \mu^p$ defines the price markup that obtains under flexible prices. Firm profits are

$$\frac{\Pi_t}{P_t} = l_t \left(1 - w_t - \frac{\xi_p}{2} z_t (\pi_t - 1)^2 \right) \quad (19)$$

2.3 Aggregation

Equations 20-26 define aggregate consumption, aggregate hours, aggregate real money balances, bonds, profits, transfers and total output:

$$c_t = (1 - \theta) c_t^u + \theta c_t^c \quad (20)$$

$$l_t = (1 - \theta) l_t^u + \theta l_t^c \quad (21)$$

$$m_t = (1 - \theta) m_t^u + \theta m_t^c \quad (22)$$

$$B_t^u = \frac{B_t}{1 - \theta} \quad (23)$$

$$\Pi_t^u = \frac{\Pi_t}{1 - \theta} \quad (24)$$

$$t_t = (1 - \theta) t_t^u + \theta t_t^c \quad (25)$$

$$y_t = (1 - \theta) c_t^u \left(1 + s \left(\frac{c_t^u}{m_t^u} \right) \right) + \theta c_t^c \left(1 + s \left(\frac{c_t^c}{m_t^c} \right) \right) + g_t + \frac{\xi_p}{2} y_t (\pi_t - 1)^2 \quad (26)$$

where g_t defines public consumption.

2.4 Government budget

The government supplies an exogenous, stochastic¹³ and unproductive amount of public good g_t and implements exogenous transfers t_t . Government financing is obtained through a labor-income tax, money creation and issuance of one-period, nominally risk free bonds. The government's flow budget constraint is then given by

$$R_{t-1} \frac{B_{t-1}}{P_t} + g_t + t_t = \tau_t w_t l_t + \frac{M_t - M_{t-1}}{P_t} + \frac{B_t}{P_t} \quad (27)$$

We assume that the government commits to repaying its debt, hence the Ramsey plan will satisfy the no Ponzi game condition:

$$\lim_{T \rightarrow \infty} E_t \beta^{T-t} B_T \leq 0 \quad (28)$$

3 Equilibrium and Ramsey policy

3.1 Rational Expectations Equilibrium

Definition 1 A rational expectations equilibrium is a set of plans

$$\{c_t^u, c_t^c, c_t, l_t^u, l_t^c, l_t, \lambda_t^u, \lambda_t^c, mc_t, \pi_t, w_t, m_t^u, m_t^c, m_t, y_t, b_t, R_t, \tau_t, t_t^u, t_t^c, t_t\}_{t=0}^{\infty},$$

that given initial values $\{m_{-1}^u, m_{-1}^c, m_{-1}, b_{-1}\}$ and stochastic processes $\{g\}_{t=0}^{\infty}$ and $\{z\}_{t=0}^{\infty}$, satisfies equations 7,8,9,10,11,12,13,14,15,17,18,20,21,22,25,26,27, the no-Ponzi game conditions 6 and 28 and the non-negativity constraint on the nominal interest rate.

3.2 Ramsey Optimal Policy

Definition 2 A Ramsey optimal policy is a rational expectations equilibrium that attains the maximum of the following additive social welfare function

$$W = E_0 \sum_{t=0}^{\infty} \beta^t ((1 - \theta) u(c_t^u, l_t^u) + \theta u(c_t^c, l_t^c)) \quad (29)$$

The Ramsey program is non-stationary, in the sense that in the initial period the Ramsey planner has an incentive to generate surprise movements in inflation or taxes. We neglect these non-stationary transitory components and concentrate on the time-invariant long run outcome, which we refer to as the Ramsey steady state. This procedure is common in the literature (see for instance Schmitt-Grohé and Uribe, 2004a).¹⁴

¹³We assume that the logarithm of government consumption is normal and i.i.d.

¹⁴Since the analytical derivation of the first order conditions of the Ramsey plan is cumbersome, we compute them using symbolic Matlab routines. The steady state of the Ramsey program is obtained using the OLS approach suggested in Stephanie Schmitt-Grohé, Martín Uribe (2011). Dynamics of the Ramsey plan around the steady state are computed using Dynare.

4 Ramsey Steady State

The first step in our analysis is the identification of the planner's incentive to use inflation as a redistributive tool, highlighting the efficiency-equity trade off. To this end we greatly simplify the model by imposing several parameter restrictions. In Model A we initially assume that leisure is not valued ($\eta = 0$), prices are flexible ($\xi_p = 0$), the discount factor β is 1, public expenditure, public debt and the labor tax are nil. Moreover, we set the parameter A in the transaction technology equal to one. Finally, we consider a separable utility function in consumption and leisure, i.e. $\sigma = 1$ and $\gamma = 1$. The planner's policy instruments are inflation and lump-sum transfers. In the second step of our analysis, Model B, we endogeneize the labor supply, allowing for positive values of η , and we assume that the planner can subsidize production by levying the inflation tax. The model is already too complex to obtain analytical solutions, and we must rely on numerical methods. To facilitate comparison with model A, we keep the restrictions adopted for β and ξ_p , and maintain that public expenditure, public debt and the labor tax are nil. All the remaining parameters are set as in the full model calibration (see Table 2). Then we compute the Ramsey solution for the full model, where the planner's problem is the identification of the optimal financing mix (inflation and labor income tax) for a given level and composition of public expenditures. This latter exercise adds to Schmitt-Grohé and Uribe (2004a) and Di Bartolomeo et al (2014) because we focus on the planner's concern for redistribution as a determinant of inflation. Throughout the paper negative transfers are ruled out. The possibility to use lump-sum taxes would eliminate the necessity to use distortionary taxation, and would imply a zero optimal inflation rate.

4.1 Model A: the planner's incentive to use inflation as a redistributive tool.

Definition 3 *The social planner allocation in model A is defined as the pair $\{c^u, c^c\}$ that maximises $(1 - \theta) \ln c^u + \theta \ln c^c$ subject to the aggregate resource constraint $(1 - \theta) c^u + \theta c^c = l = 1$.*

Proposition 1 *For $0 < \theta < 1$ the optimal pair $\{c^u, \bar{c}\}$ is defined by $c^u = c^c = 1$.*

Proof. The first order conditions with respect to c^u and c^c are respectively $\frac{\partial}{\partial c^u} = \frac{1-\theta}{c^u} - \lambda(1-\theta) = 0$ and $\frac{\partial}{\partial c^c} = \frac{\theta}{c^c} - \lambda\theta = 0$. Combining the two first order conditions, one obtains $c^u = c^c$. Given the aggregate resource constraint $(1 - \theta) c^u + \theta c^c = l = 1$, it is trivial to see that the solution is $c^c = c^u = 1$. ■

The equalization of the two levels of consumption under the first best depends on our assumptions about the concavity of the utility function. Indeed it is easy to see that under a linear utility function only the sum of the two levels of consumption would be determined, while relative consumption would not be pinned down. Under a concave utility function, the value of a small amount of additional consumption is higher at low levels of income than at high levels of income. The first best allocation cannot be reached until all agents consume at the same level.

Let us now turn to the solution of the Ramsey planner's problem.

Proposition 2 *Under the parameter restrictions imposed on Model A, the Ramsey steady state converges to the Golden Rule allocation .*

Proof. See Appendix A. ■

Proposition (2) allows us to compute the Golden Rule of Model A instead of the Ramsey steady state directly. The Golden Rule is obtained by maximising the instantaneous social welfare function

subject to the competitive equilibrium conditions after imposing the steady state on the latter. This greatly facilitates derivation of the optimal steady state. In Appendix A we substitute the constraints in the objective function and reduce the Golden Rule problem to a simple unconstrained optimization in one variable.

The problem of the planner is to choose π to maximise

$$W = (1 - \theta) \ln c^u(\pi) + \theta \ln c^c(\pi) \quad (30)$$

$c^u(\pi)$ and $c^c(\pi)$ are made explicit in Appendix A.

Proposition 3 *For $\theta = 0$ the optimal steady state inflation rate is $\pi = 1$.*

Proof. See Appendix A. ■

Proposition (3) is the standard Friedman rule result obtained under representative agent models when $\beta \rightarrow 1$. The absence of discounting makes sure that the planner adopts a policy in which no new money is printed and no transfer occurs. Monopolistic competition does not affect the result because labor is supplied inelastically and hours are always equal to one. As a result, the only potential inefficiency comes from the presence of monetary transaction costs and zero inflation assures that they are nil.

Proposition 4 *Consumption inequality is strictly decreasing in inflation.*

Proof. In Appendix A, we show that the difference between unconstrained agents' consumption and constrained agents' consumption is $c^u - c^c = \frac{(1-\rho)/(1-\theta)}{1 + \frac{B}{\sqrt{B + \frac{\pi-1}{\pi}}} + \sqrt{B + \frac{\pi-1}{\pi}} - 2\sqrt{B} + \frac{(\pi-1)/\pi}{\sqrt{B + \frac{\pi-1}{\pi}}}$. Note that $c^u - c^c = (1 - \rho) / (1 - \theta)$ when $\pi = 1$. In this case no redistribution occurs and consumption inequality is entirely determined by profits, $(1 - \rho) / (1 - \theta)$. The term $\frac{B}{\sqrt{B + \frac{\pi-1}{\pi}}} + \sqrt{B + \frac{\pi-1}{\pi}} - 2\sqrt{B}$ represents transaction costs as a share of consumption, while $\frac{(\pi-1)/\pi}{\sqrt{B + \frac{\pi-1}{\pi}}}$ is the inflation tax revenue, used to finance transfers. The derivative of transaction costs with respect to π is $\frac{\pi-1}{2\pi^3 \sqrt{(B - \frac{1}{\pi} + 1)^3}}$ which is unambiguously positive for $\pi > 1$. The derivative of the inflation tax revenue is $\frac{\pi + 2B\pi - 1}{2\pi^3 \sqrt{(B - \frac{1}{\pi} + 1)^3}}$, which is positive for $\pi \geq 1$. Since the denominator of $c^u - c^c$ is increasing in inflation for $\pi > 1$, $c^u - c^c$ is decreasing. ■

A positive inflation rate reduces inequality for two reasons. The first one is that it indirectly taxes consumption out of profits by raising¹⁵ transaction costs. As a consequence, unconstrained agents contribute more to tax revenues. This tax is obviously borne only by constrained agents who own firms. The second one is that inflation-financed transfers equally benefit the two households groups.

Proposition 5 *(Failure of the Friedman rule under agent heterogeneity) $\pi = 1$ cannot be a solution to the Ramsey planner's problem.*

Proof. See Appendix A. ■

¹⁵The inequality reducing effect of inflation would obviously be stronger if transfers only accrued to constrained households.

Since inequality is strictly decreasing in π , the planner faces a trade off between efficiency, which would be delivered by eliminating transaction costs, and equity that requires the equalization of the consumption of the two agents. Failure of the Friedman rule under agent heterogeneity depends on the fact that (46) is increasing in π when $\pi = 1$, i.e. the equity motive has a more powerful marginal effect when inflation is nil.

4.2 Model B: efficiency and redistribution when the labor supply is endogenous.

We now endogenize labor supply, allowing for $\eta > 0$. Under monopolistic competition this implies that the planner now is confronted with an efficiency problem. We therefore introduce the possibility of inflation-financed production subsidies, and investigate how the optimum subsidy is affected by agents heterogeneity.

Remark 1 *For any value of θ , an endogenous labor supply raises the optimal inflation rate. A higher inflation rate reduces *cet. par.* consumption and leisure inequality.*

In Appendix B, we show that the planner's problem can be reduced to a system of two endogenous variables, inflation and the labor tax rate (negative if production is subsidized). Figure 1 provides a graphical exposition. The schedule MW and MW' identify combinations of inflation and subsidy that maximise welfare when parameter θ takes values 0 and 0.84¹⁶ respectively. Their slopes are positive because an increase in inflation raises transaction costs and lowers the consumption value of labor effort. As a result the planner's incentive to subsidize production (and labor effort) falls. The schedule GG identifies combinations of Inflation and production subsidy that are consistent with a balanced budget constraint. Its slope is obviously negative.

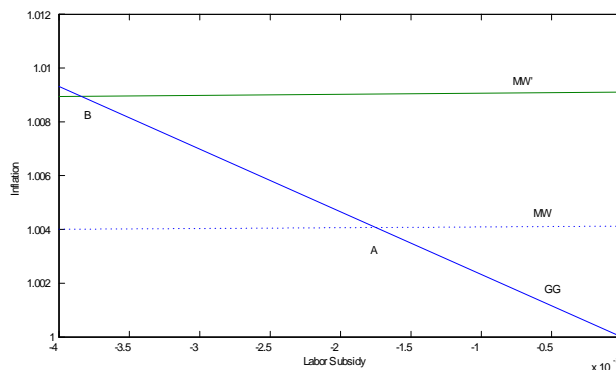


Figure 1: Blue line: Government budget equilibrium. Dotted line: Planner indifference curve under $\theta = 0$. Green line: Planner indifference curve under $\theta = 0.84$.

The Friedman rule fails even under the representative agent assumption, $\theta = 0$. To attain the first best, the planner should set $\tau = \frac{\rho-1}{\rho}$, and subsidize labor supply at a rate equal to the mark-up of prices over marginal costs. But such a policy requires funds that are costly to obtain since lump-sum taxes are not available. The only way to obtain them is through inflation, which

¹⁶This value fits the wealth Gini index for the US as we are going to explain later on.

means that to reduce monopolistic distortions, one has to increase consumption transaction costs. The trade-off is resolved at point A, with labor supply subsidized and an inflation rate above the Friedman rule level.

Under agent heterogeneity, the trade-off is resolved at higher levels of inflation and of the labor subsidy. Indeed, the planner indifference curve shifts to the left, while the government budget constraint is unaffected. The latter result follows from the fact that θ does not affect aggregate variables, i.e. total employment, consumption and therefore inflation tax revenues. The planner indifference curve, instead, requires higher levels of inflation for any given labor tax rate: the optimal combination of inflation and subsidy shifts from point A to point B.

The intuition for the result is straightforward. The inflation tax is levied on individual money holdings, so the contribution of unconstrained agents is unambiguously larger. As a matter of fact these agents suffer from a reduction in the consumption value of firms profits. This is only partly compensated for by the increase in labor income, which also accrues to constrained households. As a result consumption inequality unambiguously falls in inflation. Given the labor supply conditions (9) and (13), this implies that leisure inequality is also reduced.

4.3 The full model

We now consider the full model. The time unit is meant to be a year and we set the subjective discount rate β to 0.96 to be consistent with a steady-state real rate of return of 4 percent per year. We set ρ such that in the goods market monopolistic competition implies a gross markup of 1.2, and the annualized Rotemberg price adjustment cost is 4.375 (this implies that firms change their price on average every 9 months, see Schmitt-Grohé and Uribe, 2004a). The preference parameter η is set so that under a zero inflation steady state the average household would allocate 20 percent of the time to work¹⁷. Following Schmitt-Grohé and Uribe (2004a), transaction cost parameters A and B are set at 0.011 and 0.075, public consumption and public debt are respectively set at 19% and 44% of GDP.¹⁸ Following Di Bartolomeo et al (2014), we set the share of public transfers over GDP alternatively at 0 and 12%. We experiment with different calibrations of the share of constrained agents θ , but in the benchmark case we set it at 0.84 to fit the wealth Gini index for United States which is around 0.78¹⁹ (see Quadrini and Ríos-Rull (1997)). In Appendix C, we report the details of the computation of the model Gini index.

¹⁷This is computed when the public consumption-to-GDP ratio and public debt are nil.

¹⁸The Ramsey program is subject to steady state indeterminacy unless the long run level of public debt is not uniquely pinned down to an arbitrary value.

¹⁹The Gini coefficient is computed for a zero inflation steady state model economy and when the public consumption-to-GDP ratio and public debt are nil. The Gini coefficient changes only slightly in the presence of positive levels of public consumption and public debt.

Parameters	Model A	Model B	Full model
β	1	1	0.96
σ	1	1	1
γ	1	1	1
η	0	3.2927	3.2927
A	1	0.011	0.011
B	$B > 0$	0.011	0.075
ρ	$\rho < 1$	1/1.2	1/1.2
ξ_p	0	0	4.375
$\frac{z}{y}$	0	0	0.19
$\frac{y}{b}$	0	0	0;0.44
θ	$0 < \theta < 1$	$0 < \theta < 10.84$	$0 < \theta < 10.84$
$\frac{t}{y}$	endogenous	0	0;0.12

Table 2: Calibration

with the calibration reported in Table 2. With respect to Model B we have two major differences. We introduce sticky prices and assume that the government has to finance an exogenous stream of public expenditures, as is common in the literature. The objective of this section is to deliver quantitative predictions on the optimal steady state inflation rate.

Price stickiness implies an efficiency tradeoff between price adjustment costs that disappear at zero inflation, and monetary transaction costs that vanish at negative inflation. In addition, the introduction of exogenous public consumption expenditures makes sure that the government has to raise some revenues using either distortionary taxation or the inflation tax. For realistic calibrations of public consumption expenditure, the standard result is that the Ramsey planner finds it optimal to finance it almost completely by levying labor taxes rather than by printing money, and the optimal steady state inflation rate is slightly below zero (see Schmitt-Grohé and Uribe, 2004a). Di Bartolomeo et al (2014) show that public-transfers-to-GDP ratios in the range observed for developed economies may instead induce the planner to choose relatively high inflation rates.

We assess the robustness of such results to the introduction of agent heterogeneity. First, we assume that public spending only consists of public consumption. Then, we introduce public transfers, assuming that they only accrue to constrained agents.²⁰ Finally we consider the case where transfers are equally earned by the two agents' groups (Table 3).

	$\theta = 0$	$\theta = 0.2$	$\theta = 0.4$	$\theta = 0.6$	$\theta = 0.8$	$\theta = 0.84$
A	-0.69%	-0.68%	-0.63%	-0.59%	-0.56%	-0.53%
B	-	2.21%	2.15%	2.4%	3.55%	4.36%
C	2.11%	2.21%	2.4%	2.75%	4.1%	5.05%

Table 3: Optimal Inflation Rates. A: Model without public transfers and public debt.

B: Model with (12%) public transfers accruing only to constrained agents and public debt

C: Model with (12%) public transfers equally shared by agents and public debt

In the absence of public transfers and public debt, the optimal inflation rate increases in θ , but the increase is negligible and the prescription of a slightly negative inflation rate remains unaffected.

²⁰In this latter case, we also consider positive levels of public debt, which increase inequality.

When the share of constrained agents is calibrated to match the empirical wealth Gini index for the US (0.78), the optimal inflation rate is -0.53%. When public debt is calibrated at 44% of GDP, the optimal inflation rate grows slightly, due to the fact that debt increases inequality. But the real difference is made by transfers. If we allow for a 12% transfers to GDP ratio and the value of θ allows to match the empirical Gini index, the optimal inflation rate grows up to 4.36%. Notice that this is true notwithstanding the fact that transfers accrue only to constrained agents, an assumption that strongly reduces inequality. The optimal inflation rate is even higher if transfers are equally shared among all agents.

To summarize the results, introducing agent heterogeneity tends to increase the optimal inflation rate. Indeed, the inflation tax weighs more on unconstrained agents, who consume more and hold a higher level of money balances, while the opposite is true for the labor tax. When LAMP is combined with the presence of exogenous public transfers, the effect on the optimal inflation rate is important.

5 Ramsey dynamics

In this section we compute the optimal dynamics for the full model, in the presence of i.i.d. government consumption shocks. We compare the heterogenous agent model to the representative agent model. In the heterogenous agent case we set $\theta = 0.84$. To facilitate comparison with Schmitt-Grohè and Uribe (2004a) we keep public debt at 44% of GDP and we assume away public transfers. Figures 2 and 3 report the impulse response functions of the main variables to a 1% standard deviation government consumption shock.

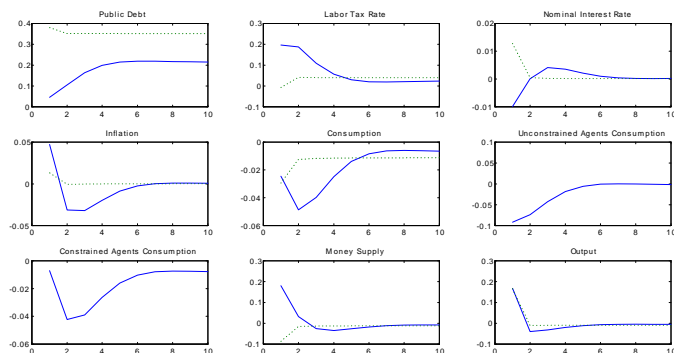


Figure 2: Response to a government consumption shock. Blue line: heterogenous agents model. Dotted line: representative agent model. - Percentage deviation from the steady state.

The optimal response of variables to a government spending shock under the representative agent assumption is well known in the literature (see Schmitt-Grohè and Uribe, 2004a). The trade off between stabilising inflation to avoid price adjustment costs and keeping the nominal interest rate constant to avoid swings in transaction costs is resolved in favor of the former: the Ramsey planner almost completely stabilises inflation. Indeed, the nominal interest rate grows and inflation responds only slightly. Public debt is used as a cushion to stabilise tax rates and is increased permanently. In such a setting, public debt follows a near-random walk.

Under agents heterogeneity, the behaviour of the Ramsey planner changes in a fundamental way. Instead of stabilising inflation and the labor tax rate, it is optimal to let them respond positively to the shock, even though public debt retains the unit root feature. The response of the nominal interest rate is negative: the increase in government consumption is accomodated by monetary policy. This results in a strongly positive reaction of the real money supply. While under the representative agent model public debt jumps on a new steady state on impact, under agent heterogeneity the transition of public debt to a higher level is slower. Moreover the new level is lower than under the representative agent model. The Ramsey planner finds it optimal to front-load tax adjustment and to keep public debt more stable. Notice that such relevant differences in the optimal trajectory of policy instruments do not result in a different behaviour of output, whose response is almost not affected by agent heterogeneity. Aggregate consumption response is hump-shaped and its fall is more persistent. Unconstrained agents suffer more from the shock. Their consumption falls strongly at impact, while the fall in the consumption of constrained agents is more gradual and reaches its low after one year.

To summarize, agent heterogeneity makes it optimal to finance government spending shocks through taxes and inflation rather than almost completely by increasing government debt. The response of output is not affected by agent heterogeneity, while aggregate consumption falls gradually, rather than falling at impact and recovering rapidly. The response of aggregate consumption is the composition of a strong and prolonged slump of unconstrained agents' consumption and of a more gradual and less intense slowdown of constrained agents' consumption.

6 Conclusions

The focus of this paper is to study the effect of agent heterogeneity, in the form of limited participation to the market for interest bearing assets, on the optimal inflation rate in an otherwise standard DSGE model akin to Schmitt-Grohè and Uribe (2004a) and Di Bartolomeo et al (2014). We question the widely held belief that a higher trend inflation rate entails a higher level of inequality (Erosa and Ventura (2002), Albanesi (2007)). We highlight that when the relationship between inflation and inequality is assessed in a model which is routinely used to study optimal policy issues, the main mechanism works indeed in the opposite direction. As unconstrained agents are the only owners of firms, they are the only earners of profit income. As a consequence, they consume more and hold higher money balances than constrained agents. A higher trend inflation rate constitutes a tax on the consumption value of profits.

We highlight the basic mechanism in a stripped down version of the model, where the Ramsey planner can raise the inflation rate to finance lump-sum transfers and labor supply is fixed. We find that under agent heterogeneity it is optimal to increase both the inflation rate and transfers above the representative agent counterpart. A higher inflation rate generates revenues which are financed for the major part by unconstrained agents, while transfers are equally shared. As a consequence, higher inflation entails lower inequality. A similar result holds when labor supply is endogenous and inflation can be used to finance production subsidies.

In the full model, agent heterogeneity strenghten the result obtained by Di Bartolomeo et al (2014) that in the presence of public transfers the optimal inflation rate is compatible with observed central banks' targets. The optimal inflation rate increases in the share of constrained agents and is higher than 4% when θ is calibrated to fit the wealth Gini index for the US. This result holds also when transfers are used to redistribute income.

Finally we obtain the optimal response to a government consumption shock. We find that agent heterogeneity renders optimal to front-load tax adjustment, letting labor taxes and inflation respond more strongly. Public debt transitions to a new and higher equilibrium but more slowly than under the representative agent model. The optimal output response is unaffected by agent heterogeneity but aggregate consumption follows a hump-shaped trajectory instead of a strong fall and a rapid recovery. This results from the interaction of a deep and prolonged slump of unconstrained agents' consumption and a gradual and less marked decline in constrained agents' consumption.

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Appendix A

Proof of Proposition 2

Under the assumptions of flexible prices ($\xi_p = 0$), exogenous labor supply ($\eta = 0$) and in the absence of stochastic shocks, the production side of the model collapses to the trivial equality $w_t = \rho$, as can be easily seen from eq. 17. Since leisure is not valued, both households work all the time and $l_t^c = l_t^u = l_t = 1$. Hence, output and the real wage are constants. Profits are constant too and equal to $1 - \rho$. In such a setting, equations (9) and (13) disappear and, after some substitutions

and manipulations, the competitive equilibrium of the model collapses to the following system of equations:

$$1 - \left[\frac{\beta}{\pi_{t+1}} \frac{\frac{u_c(c_{t+1}^c)}{1+s(\frac{c_{t+1}^c}{m_{t+1}^c})+\frac{c_{t+1}^c}{m_{t+1}^c} s'(\frac{c_{t+1}^c}{m_{t+1}^c})}}{\frac{u_c(c_t^c)}{1+s(\frac{c_t^c}{m_t^c})+\frac{c_t^c}{m_t^c} s'(\frac{c_t^c}{m_t^c})}} \right] = s'(\frac{c_t^c}{m_t^c}) \left(\frac{c_t^c}{m_t^c} \right)^2 \quad (31)$$

$$1 - \left[\frac{\beta}{\pi_{t+1}} \frac{\frac{u_u(c_{t+1}^u)}{1+s(\frac{c_{t+1}^u}{m_{t+1}^u})+\frac{c_{t+1}^u}{m_{t+1}^u} s'(\frac{c_{t+1}^u}{m_{t+1}^u})}}{\frac{u_u(c_t^u)}{1+s(\frac{c_t^u}{m_t^u})+\frac{c_t^u}{m_t^u} s'(\frac{c_t^u}{m_t^u})}} \right] = s'(\frac{c_t^u}{m_t^u}) \left(\frac{c_t^u}{m_t^u} \right)^2 \quad (32)$$

$$c_t^u \left(1 + s(\frac{c_t^u}{m_t^u}) \right) + m_t^u + \frac{B_t^u}{P_t} = \rho + \frac{m_{t-1}^u}{\pi_t} + \frac{(1-\rho)}{1-\theta} + \frac{R_{t-1}B_{t-1}^u}{P_t} + t_t \quad (33)$$

$$c_{t,i}^c \left(1 + s(\frac{c_t^c}{m_t^c}) \right) + m_t^c = \rho + \frac{m_{t-1}^c}{\pi_t} + t_t. \quad (34)$$

$$R_{t-1} \frac{B_{t-1}}{P_t} + g + t_t = (1-\theta) \left(m_t^u - \frac{m_{t-1}^u}{\pi_t} \right) + \theta \left(m_t^c - \frac{m_{t-1}^c}{\pi_t} \right) + \frac{B_t}{P_t} \quad (35)$$

The Ramsey planner maximises the social welfare function under the constraints given by the competitive equilibrium conditions, before imposing the steady state solution on the latter. Assuming that the government budget is always in equilibrium and public consumption is zero, the Lagrangean is:

$$L = \sum_{t=0}^{\infty} \beta^t \left((1-\theta) u(c_t^u) + \theta u(c_t^c) \right) - \sum_{t=0}^{\infty} \beta^t \left\{ \begin{array}{l} \phi_{1,t} \left[1 - \left(\frac{\frac{u_u(c_{t+1}^u)}{1+s(\frac{c_{t+1}^u}{m_{t+1}^u})+\frac{c_{t+1}^u}{m_{t+1}^u} s'(\frac{c_{t+1}^u}{m_{t+1}^u})}}{\frac{u_u(c_t^u)}{1+s(\frac{c_t^u}{m_t^u})+\frac{c_t^u}{m_t^u} s'(\frac{c_t^u}{m_t^u})}} \right) - s'(\frac{c_t^u}{m_t^u}) \left(\frac{c_t^u}{m_t^u} \right)^2 \right] \\ + \phi_{2,t} \left[c_t^u \left(1 + s(\frac{c_t^u}{m_t^u}) \right) + m_t^u - \rho - \frac{m_{t-1}^u}{\pi_t} - \frac{(1-\rho)}{1-\theta} - t_t \right] \\ + \phi_{3,t} \left[1 - \left(\frac{\frac{u_c(c_{t+1}^c)}{1+s(\frac{c_{t+1}^c}{m_{t+1}^c})+\frac{c_{t+1}^c}{m_{t+1}^c} s'(\frac{c_{t+1}^c}{m_{t+1}^c})}}{\frac{u_c(c_t^c)}{1+s(\frac{c_t^c}{m_t^c})+\frac{c_t^c}{m_t^c} s'(\frac{c_t^c}{m_t^c})}} \right) - s'(\frac{c_t^c}{m_t^c}) \left(\frac{c_t^c}{m_t^c} \right)^2 \right] \\ + \phi_{4,t} \left[c_{t,i}^c \left(1 + s(\frac{c_t^c}{m_t^c}) \right) + m_t^c - \rho - \frac{m_{t-1}^c}{\pi_t} - t_t \right] \\ + \phi_{5,t} \left[t_t - (1-\theta) \left(m_t^u - \frac{m_{t-1}^u}{\pi_t} \right) - \theta \left(m_t^c - \frac{m_{t-1}^c}{\pi_t} \right) \right] \end{array} \right\}$$

$$-\frac{1}{\beta} \left\{ \begin{array}{l} \phi_{1,-1} \left[1 - \left(\frac{\frac{u_u(c_0^u)}{1+s(\frac{c_0^u}{m_0^u})+\frac{c_0^u}{m_0^u}s'(\frac{c_0^u}{m_0^u})}}{\frac{u_u(c_{-1}^u)}{1+s(\frac{c_{-1}^u}{m_{-1}^u})+\frac{c_{-1}^u}{m_{-1}^u}s'(\frac{c_{-1}^u}{m_{-1}^u})}} \right) = s'(\frac{c_{-1}^u}{m_{-1}^u}) \left(\frac{c_{-1}^u}{m_{-1}^u} \right)^2 \right] \\ +\phi_{3,-1} \left[1 - \left(\frac{\frac{u_c(c_0^c)}{1+s(\frac{c_0^c}{m_0^c})+\frac{c_0^c}{m_0^c}s'(\frac{c_0^c}{m_0^c})}}{\frac{u_c(c_{-1}^c)}{1+s(\frac{c_{-1}^c}{m_{-1}^c})+\frac{c_{-1}^c}{m_{-1}^c}s'(\frac{c_{-1}^c}{m_{-1}^c})}} \right) - s'(\frac{c_{-1}^c}{m_{-1}^c}) \left(\frac{c_{-1}^c}{m_{-1}^c} \right)^2 \right] \end{array} \right\}$$

Assuming $\sigma = 1$ and $A = 1$, computing the first order conditions, imposing the steady state and taking the limit of the resulting equations for $\beta \rightarrow 1$ gives rise to the following system of equations:

$$\frac{\partial L}{\partial c^u} = 2\sqrt{B}(1 - \phi_2) + \frac{1}{c^u}(1 - \theta) - \frac{2c^u\phi_1}{(m^u)^2} - \frac{2c^u\phi_2}{m^u} = 0 \quad (36)$$

$$\frac{\partial L}{\partial c^c} = \frac{\theta}{c^c} - \phi_4 \left(\frac{c^c}{m^c} - 2\sqrt{B} + c^c \left(\frac{1}{m^c} - \frac{Bm^c}{(c^c)^2} \right) + \frac{Bm^c}{c^c} + 1 \right) - \frac{2\phi_3c^c}{(m^c)^2} = 0 \quad (37)$$

$$\frac{\partial L}{\partial m^u} = \frac{2(c^u)^2\phi_1}{(m^u)^3} - \phi_2 \left(c^u \left(\frac{B}{c^u} - \frac{c^u}{(m^u)^2} \right) - \frac{1}{\pi} + 1 \right) - \phi_5(1 - \theta) \left(\frac{1}{\pi} - 1 \right) = 0 \quad (38)$$

$$\frac{\partial L}{\partial m^c} = \frac{2(c^c)^2\phi_3}{(m^c)^3} - \phi_4 \left(c^c \left(\frac{B}{c^c} - \frac{c^c}{(m^c)^2} \right) - \frac{1}{\pi} + 1 \right) - \phi_5\theta \left(\frac{1}{\pi} - 1 \right) = 0 \quad (39)$$

$$\frac{\partial L}{\partial \pi} = \frac{\phi_1 + \phi_3 + m^u(\phi_5(1 - \theta) - \phi_2) + m^c(\phi_5\theta - \phi_4)}{\pi^2} = 0 \quad (40)$$

$$\frac{\partial L}{\partial t} = (\phi_2 + \phi_4 - \phi_5) = 0 \quad (41)$$

The Golden rule equilibrium is obtained by maximising the instantaneous social welfare function under the constraints given by the competitive equilibrium condition after imposing the steady state on the latter. In this case the Lagrangian is:

$$L = ((1 - \theta)u(c^u) + \theta u(c^c)) - \left\{ \begin{array}{l} \phi_1 \left[1 - \frac{\beta}{\pi} - s'(\frac{c^u}{m^u}) \left(\frac{c^u}{m^u} \right)^2 \right] \\ +\phi_2 \left[c^u \left(1 + s(\frac{c^u}{m^u}) \right) + m^u - \rho - \frac{m^u}{\pi} - \frac{(1-\rho)}{1-\theta} - t \right] \\ +\phi_3 \left[1 - \left(\frac{\beta}{\pi} \right) - s'(\frac{c^c}{m^c}) \left(\frac{c^c}{m^c} \right)^2 \right] \\ +\phi_4 \left[c^c \left(1 + s(\frac{c^c}{m^c}) \right) + m^c - \rho - \frac{m^c}{\pi} - t \right] \\ +\phi_{5,t} \left[t - (1 - \theta) \left(m^u - \frac{m^u}{\pi} \right) - \theta \left(m^c - \frac{m^c}{\pi} \right) \right] \end{array} \right\}$$

Computing the first order conditions and taking their value for $\beta = 1$ gives again equations (36)-(41). A similar result holds also for $\eta > 0$. The proof is available upon request.

Proof of Proposition 3

Imposing the steady state condition on equations (31) and (32) and making them explicit, we obtain that $\frac{c^u}{m^u} = \frac{c^c}{m^c} = \sqrt{\frac{\pi-\beta}{\pi}} + B$.²¹ Assuming that debt and public consumption are zero, we can solve equation (35) for t and substitute the value we obtain in equations (33) and (34). Imposing the steady state on the resulting equations and substituting for the consumption to money ratio, we get:

$$c^u = c^c + \frac{(1-\rho)}{(1-\theta) \left(1 + 2\sqrt{\frac{\pi-1}{\pi}} + B - 2\sqrt{B}\right)} \quad (42)$$

$$c^c = \frac{\rho + c \frac{\frac{\pi-1}{\pi}}{\sqrt{\frac{\pi-1}{\pi}} + B}}{\left(1 + 2\sqrt{\frac{\pi-1}{\pi}} + B - 2\sqrt{B}\right)} \quad (43)$$

where $c = (1-\theta)c^u \frac{\frac{\pi-1}{\pi}}{\sqrt{\frac{\pi-1}{\pi}} + B} + \theta c^c \frac{\frac{\pi-1}{\pi}}{\sqrt{\frac{\pi-1}{\pi}} + B}$, $c \frac{\frac{\pi-1}{\pi}}{\sqrt{\frac{\pi-1}{\pi}} + B}$ defines the increase in labor income caused by the transfer financed by the inflation tax, $\frac{(1-\rho)}{(1-\theta) \left(1 + 2\sqrt{\frac{\pi-1}{\pi}} + B - 2\sqrt{B}\right)}$ defines unconstrained agents' consumption out of profits. It is now straightforward that $c^u - c^c = \frac{(1-\rho)}{(1-\theta) \left(1 + 2\sqrt{\frac{\pi-1}{\pi}} + B - 2\sqrt{B} + \frac{\frac{\pi-1}{\pi}}{\sqrt{\frac{\pi-1}{\pi}} + B}\right)}$ falls with inflation.

Solving the system given by equations (42) and (43), we can express consumption of the two agents as a function of inflation only. We obtain:

$$c^c(\pi) = \frac{\rho + (1-\theta) \frac{\rho + \left(1 + \theta \frac{\frac{\pi-1}{\pi}}{\sqrt{\frac{\pi-1}{\pi}} + B} + \frac{B}{\sqrt{\frac{\pi-1}{\pi}} + B} - 2\sqrt{B} + \frac{\frac{\pi-1}{\pi}}{\sqrt{\frac{\pi-1}{\pi}} + B} (1-\theta)\right) \frac{(1-\rho)}{1-\theta}}{1 + \sqrt{\frac{\pi-\beta}{\pi}} + B + \frac{B}{\sqrt{\frac{\pi-\beta}{\pi}} + B} - 2\sqrt{B} + \theta \left(\frac{\frac{\pi-1}{\pi}}{\sqrt{\frac{\pi-\beta}{\pi}} + B} - \frac{(1-\theta) \frac{(\frac{\pi-1}{\pi})^2}{\frac{\pi-\beta}{\pi}}}{1 + \sqrt{\frac{\pi-\beta}{\pi}} + B + \frac{B}{\sqrt{\frac{\pi-\beta}{\pi}} + B} - 2\sqrt{B} + \frac{\frac{\pi-1}{\pi}}{\sqrt{\frac{\pi-\beta}{\pi}} + B} (1-\theta)} \right)} \frac{\frac{\pi-1}{\pi}}{\sqrt{\frac{\pi-\beta}{\pi}} + B}}{1 + \sqrt{\frac{\pi-\beta}{\pi}} + B + \frac{B}{\sqrt{\frac{\pi-\beta}{\pi}} + B} - 2\sqrt{B} + \frac{\frac{\pi-1}{\pi}}{\sqrt{\frac{\pi-\beta}{\pi}} + B} (1-\theta)} \quad (44)$$

²¹Here we are again assuming $A=1$.

$$c^u(\pi) = \frac{\rho \left(1 + \theta \frac{\frac{\frac{\pi-1}{\pi}}{\sqrt{\frac{\pi-\beta}{\pi} + B}}}}{1 + \sqrt{\frac{\pi-\beta}{\pi} + B} + \frac{B}{\sqrt{\frac{\pi-\beta}{\pi} + B}} - 2\sqrt{B} + \frac{\frac{\pi-1}{\pi}}{\sqrt{\frac{\pi-\beta}{\pi} + B}}(1-\theta)} \right) + \frac{(1-\rho)}{1-\theta}}{\left\{ \begin{array}{l} 1 + \sqrt{\frac{\pi-\beta}{\pi} + B} + \frac{B}{\sqrt{\frac{\pi-\beta}{\pi} + B}} - 2\sqrt{B} + \\ \theta \left(\frac{\frac{\pi-1}{\pi}}{\sqrt{\frac{\pi-\beta}{\pi} + B}} - \frac{(1-\theta) \left(\frac{\pi-1}{\pi} \right)^2}{1 + \sqrt{\frac{\pi-\beta}{\pi} + B} + \frac{B}{\sqrt{\frac{\pi-\beta}{\pi} + B}} - 2\sqrt{B} + \frac{\frac{\pi-1}{\pi}}{\sqrt{\frac{\pi-\beta}{\pi} + B}}(1-\theta)} \right) \end{array} \right\}} \quad (45)$$

We can now rewrite the Golden Rule problem as an unconstrained optimization in just one variable; i.e. inflation. The problem is the following:

$$\max_{\pi} (1 - \theta) \log(c^u(\pi)) + \theta \log(c^c(\pi)) \quad (46)$$

where $c^c(\pi)$ $c^u(\pi)$ are defined by eq. (44) and (45) respectively. To prove proposition (3), we assume $\theta = 0$. Then we compute the first order condition of problem (46) using symbolic Matlab routines and we obtain the following expression:

$$\frac{\frac{\pi-1}{\pi} \frac{1}{2\pi^2 \sqrt{B + \frac{\pi-1}{\pi}}}}{\left(\frac{\pi-1}{\pi} + B \right) \left(1 + \sqrt{\frac{\pi-1}{\pi} + B} + \frac{B}{\sqrt{\frac{\pi-1}{\pi} + B}} - 2\sqrt{B} \right)} = 0 \quad (47)$$

It is easy to see that the solution of equation (47) requires $\pi = 1$.²²

Proof of Proposition 5

The first order condition of problem (46), for $\theta > 0$, reads as follows:

$$\frac{c^c(\pi)}{c^u(\pi)} = -\frac{\theta}{1-\theta} \frac{c^{c'}(\pi)}{c^{u'}(\pi)} \quad (48)$$

To proof that zero inflation cannot be a solution, it is enough to show that $\frac{c^c(\pi=1)}{c^u(\pi=1)} < 1$ and $1 = -\frac{\theta}{1-\theta} \frac{c^{c'}(\pi=1)}{c^{u'}(\pi=1)}$. To show that $\frac{c^c(\pi=1)}{c^u(\pi=1)} < 1$ subtract equation (43) from (42) and obtain $c^u - c^c = \frac{(1-\rho)/(1-\theta)}{1 + \frac{B}{\sqrt{B + \frac{\pi-1}{\pi}}} + \sqrt{B + \frac{\pi-1}{\pi}} - 2\sqrt{B} + \frac{(\pi-1)/\pi}{\sqrt{B + \frac{\pi-1}{\pi}}}} = (1-\rho)/(1-\theta)$ when $\pi = 1$. Then note that

$$\begin{aligned} & (1-\theta) c^{u'}(\pi) + \theta c^{c'}(\pi) = \\ & - \left(\frac{1-\rho}{1-\theta} + \rho \right) \left(\frac{1}{\pi} - \frac{\pi-1}{\pi^2} \right) (\pi-1) \\ & \frac{2\pi \sqrt{\frac{\pi-1}{\pi} + B} \left(2B - 2\sqrt{B} \sqrt{\frac{\pi-1}{\pi} + B} + \frac{\pi-1}{\pi} + \sqrt{\frac{\pi-1}{\pi} + B} \right)^2}{\end{aligned} \quad (49)$$

²²Equation 47 is never equal to zero for $\pi \neq 1$ and its derivative (the second order condition) is negative in $\pi = 1$, hence $\pi = 1$ is a global maximum.

Expression (49) collapses to zero if $\pi = 1$, hence $1 = -\frac{\theta}{1-\theta} \frac{c^c(\pi=1)}{c^u(\pi=1)}$ holds. We now show that (46) is increasing in π when $\pi = 1$ that is

$$\frac{\theta}{c^c(\pi=1)} c^{c'}(\pi=1) + \frac{1-\theta}{c^u(\pi=1)} c^{u'}(\pi=1) > 0. \quad (50)$$

Since we showed that $(1-\theta) c^{u'}(\pi=1) = -\theta c^{c'}(\pi=1)$, we can rewrite (50) as follows

$$\theta c^{c'}(\pi=1) \left(\frac{1}{c^c(\pi=1)} - \frac{1}{c^u(\pi=1)} \right) > 0 \quad (51)$$

which holds because $c^c(\pi=1) < c^u(\pi=1)$. Since transaction costs are strictly increasing in π , this is enough to prove that the optimal inflation rate is positive and finite.

Appendix B

The competitive equilibrium conditions are given by equations (31), (32) and:

$$c_t^u \left(1 + s \left(\frac{c_t^u}{m_t^u} \right) \right) + m_t^u + \frac{B_t^u}{P_t} = (1 - \tau_t) \rho l_t^u + \frac{m_{t-1}^u}{\pi_t} + \frac{(1-\rho) \left((1-\theta) l_t^u + \theta l_t^c \right)}{1-\theta} + \frac{R_{t-1} B_{t-1}^u}{P_t} \quad (52)$$

$$c_{t,i}^c \left(1 + s \left(\frac{c_t^c}{m_t^c} \right) \right) + m_t^c = (1 - \tau_t) \rho l_t^c + \frac{m_{t-1}^c}{\pi_t} \quad (53)$$

$$(1 - \tau_t) \rho = \frac{\eta}{1 - l_t^u} c_t^u \left(1 + 2s \left(\frac{c_t^u}{m_t^u} \right) - 2\sqrt{B} \right) \quad (54)$$

$$(1 - \tau_t) \rho = \frac{\eta}{1 - l_t^c} c_t^c \left(1 + 2s \left(\frac{c_t^c}{m_t^c} \right) - 2\sqrt{B} \right) \quad (55)$$

$$R_{t-1} \frac{B_{t-1}}{P_t} + g = \tau_t \rho \left((1-\theta) l_t^u + \theta l_t^c \right) + (1-\theta) \left(m_t^u - \frac{m_{t-1}^u}{\pi_t} \right) + \theta \left(m_t^c - \frac{m_{t-1}^c}{\pi_t} \right) + \frac{B_t}{P_t} \quad (56)$$

Equations (31), (32) and (52)-(55) can be combined in the same way adopted in Appendix A. In this case we obtain the consumption levels of the two agents as a function of inflation and labor taxes:

$$c^u(\pi, \tau) = \quad (57)$$

$$(1-\rho) \left(\theta + \theta \left(\frac{\eta \left(2A \sqrt{\frac{\pi-\beta}{\pi} + B} - 2\sqrt{AB} + 1 \right)}{\sqrt{\frac{\pi-\beta}{\pi} + B} + \eta \left(2A \sqrt{\frac{\pi-\beta}{\pi} + B} - 2\sqrt{AB} + 1 \right) + \frac{\pi-1}{\pi} - 2\sqrt{AB} + \sqrt{\frac{B}{\frac{\pi-\beta}{\pi} + B}} + 1} \right) - 1 \right)$$

$$\frac{(1-\tau)\rho + \frac{\eta \left(2A \sqrt{\frac{\pi-\beta}{\pi} + B} - 2\sqrt{AB} + 1 \right)}{\theta-1}}{\left\{ \begin{array}{l} \sqrt{\frac{\pi-\beta}{\pi} + B} + \eta \left(2A \sqrt{\frac{\pi-\beta}{\pi} + B} - 2\sqrt{AB} + 1 \right) + \sqrt{\frac{\pi-1}{\pi} + \frac{\pi-\beta}{\pi} + B} \\ -2\sqrt{AB} + \frac{B}{\sqrt{\frac{\pi-\beta}{\pi} + B}} - \frac{\eta(\rho-1) \left(2A \sqrt{\frac{\pi-\beta}{\pi} + B} - 2\sqrt{AB} + 1 \right)}{\rho(1-\tau)} + 1 \end{array} \right\}}$$

$$c^c(\pi, \tau) = \frac{\rho(1-\tau)}{\left\{ \begin{aligned} &\sqrt{\frac{\pi-\beta+B}{\pi A}} + \eta \left(2A\sqrt{\frac{\pi-\beta+B}{\pi A}} - 2\sqrt{AB} + 1 \right) \\ &+ \frac{\pi-1}{\sqrt{\frac{\pi-\beta+B}{\pi A}}} - 2\sqrt{AB} + \frac{B}{\sqrt{\frac{\pi-\beta+B}{\pi A}}} + 1 \end{aligned} \right\}} \quad (58)$$

Equations (57) and (58) can be used to express also equation (56) as a function of labor taxes and inflation only:

$$BUDG(\pi, \tau) \equiv \tau\rho((1-\theta)l^u + \theta l^c) + (1-\theta)\left(m^u - \frac{m^u}{\pi}\right) + \theta\left(m^c - \frac{m^c}{\pi}\right) = 0$$

where $l^i = 1 - \frac{\eta}{\rho(1-\tau)}c^i(\pi, \tau)\left(1 + 2A\sqrt{\frac{\pi-\beta+B}{\pi A}} - 2\sqrt{AB}\right)$ and $m^i = c^i(\pi, \tau)\sqrt{\frac{A}{\frac{\pi-\beta+B}{\pi}}}$, $i = u, c$. The problem of the planner can be written as:

$$\begin{aligned} &\max_{\pi, \tau} W(\pi, \tau) \equiv \quad (59) \\ &(1-\theta) \left[\log(c^u(\pi, \tau)) + \eta \log\left(\frac{\eta}{\rho(1-\tau)}c^u(\pi, \tau)\left(1 + 2A\sqrt{\frac{\pi-\beta+B}{\pi A}} - 2\sqrt{AB}\right)\right) \right] + \\ &\theta \left[\log(c^c(\pi, \tau)) + \eta \log\left(\frac{\eta}{\rho(1-\tau)}c^c(\pi, \tau)\left(1 + 2A\sqrt{\frac{\pi-\beta+B}{\pi A}} - 2\sqrt{AB}\right)\right) \right] \\ &s.t. \quad BUDG(\pi, \tau) = 0 \end{aligned}$$

Using symbolic Matlab routines, we compute the first order conditions of problem (59). We define ϕ the Lagrange multiplier on the government budget constraint and obtain:

$$\frac{\partial W(\pi, \tau)}{\partial \pi} = \phi \frac{\partial BUDG(\pi, \tau)}{\partial \pi} \quad (60)$$

$$\frac{\partial W(\pi, \tau)}{\partial \tau} = \phi \frac{\partial BUDG(\pi, \tau)}{\partial \tau} \quad (61)$$

$$BUDG(\pi, \tau) = 0 \quad (62)$$

Combining equations (60) and (61), we can write

$$\frac{\partial W(\pi, \tau)}{\partial \pi} / \frac{\partial BUDG(\pi, \tau)}{\partial \pi} = \frac{\partial W(\pi, \tau)}{\partial \tau} / \frac{\partial BUDG(\pi, \tau)}{\partial \tau} \quad (63)$$

that describes the planner's desired marginal rate of substitution between inflation and the labor tax, which implies an increasing relationship between the two instruments. The intersection between it and equation (62) is the solution to the planner's problem.

Appendix C: Wealth Gini Index

The steady state wealth of constrained agents is given by their money holdings, m^c . The steady state wealth of unconstrained agents is given by their money holdings, their holdings of public debt and their holding of firm shares. Letting the real steady state value of firms be q , we can define the wealth of the two agents as follows:

$$w^c = m^c \quad (64)$$

$$w^u = m^u + \frac{B}{1-\theta} + \frac{q}{1-\theta} \quad (65)$$

Notice that the value of firms is given by the discounted value of future profits. In the deterministic steady state, future profits are known and constant, hence firms can be priced using the pricing formula of a perpetuity:

$$q = \frac{1}{R-1} \frac{\Pi}{P} = \frac{\beta}{1-\beta} \frac{\Pi}{P} \quad (66)$$

Total wealth is given by $w = m + B + q$. Constrained agents, who represent a share θ of the model population, hold a fraction $\theta \frac{w^c}{w}$ of total wealth, while unconstrained agents hold a fraction of wealth equal to $1 - \theta \frac{w^c}{w}$. Figure reports the Lorenz curve for $\theta = 0.8$.

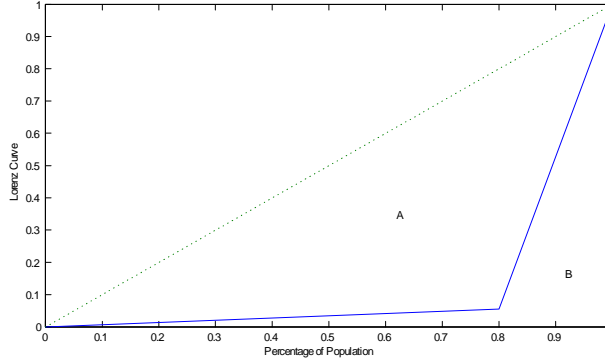


Figure xx: Blue Line: Lorenz curve. Dotted line: line of full equality

The Gini index is given by $1-2B$, where B is the area reported in Figure (in the figure we set $\theta = 0.8$). Area B can be easily computed, using the formulae for the areas of triangles and trapezoids, as $B = \left(\frac{\theta^2 \frac{w^c}{w}}{2} + \frac{(1+\theta \frac{w^c}{w})(1-\theta)}{2} \right)$. The Gini index is $1 - 2 \left(\frac{\theta^2 \frac{w^c}{w}}{2} + \frac{(1+\theta \frac{w^c}{w})(1-\theta)}{2} \right)$.

Optimal Fiscal and Monetary Policies under Limited Asset Market Participation

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Abstract

We reconsider the issue of optimal monetary and fiscal policy in a fully fledged DSGE model augmented for a share of agents excluded from asset market participation (Rule of Thumb consumers) when many fiscal instruments are available. Limited asset market participation entails a stronger use of the consumption tax in place of the labor tax in steady state. Along the business cycle, monetary policy stabilizes inflation while fiscal policy can play an important role in attenuating the effect of productivity shocks on income distribution.

Jel codes: E63, E58, E32.

Keywords: trend inflation, monetary and fiscal policy, Ramsey plan, Limited Asset Market Participation.

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1 Introduction

The standard normative result in New Keynesian models characterized by price stickiness is that monetary policy can replicate the flexible price allocation by completely stabilizing inflation (Blanchard and Gali, 2007), which renders the role of fiscal policy of secondary importance. Under medium scale DSGE models with nominal and real rigidities, monetary policy remains the main tool for business cycle stabilization; while optimal fiscal policy is passive (Schmitt-Grohè and Uribe, 2007). Standard New Keynesian DSGE models rest on the representative agent assumption which is only valid as long as everybody participates to financial markets and marginal rates of substitution are equalized among agents. Such assumptions are at odds with the data, as shown by a growing body of literature (see, for instance, Vissing-Jorgensen, 2002). A convenient device to introduce heterogeneity in a standard DSGE model has been used in a second strand of New Keynesian literature which, following a seminal contribution by Mankiw (2000), emphasizes the role of rule-of-thumb (RT henceforth) consumers who do not participate to financial markets and therefore cannot save or borrow. Gali, Lopez-Salido, and Valles (2007) as well as Furlanetto and Seneca (2009) show that this form of limited asset market participation (LAMP henceforth) can rationalize the empirically observed response of aggregate consumption to public spending shocks. In Furlanetto and Seneca (2012), the LAMP hypothesis helps account for recent empirical evidence on productivity shocks. In this paper we show that fiscal policy, besides allowing for valuable income redistribution in steady state, can reduce sub-optimal swings in income distribution along the business cycle.

Optimal monetary and fiscal policy has been already investigated under the LAMP hypothesis. Ascari et al (2011) find that optimal monetary policy is unaffected by the LAMP hypothesis, if both prices and wages are sticky: the Ramsey planner reduces inflation volatility to almost zero. Motta and Tirelli (2012) find that consumption habits reverse the latter result and make fiscal activism necessary for optimality. These studies consider simple models in which capital is not present and the fiscal sector is not fully articulated.

The present paper reconsiders the optimality issue in a fully fledged DSGE model with capital, nominal rigidities and real rigidities, in which the fiscal instruments at the disposal of the planner are many and an exogenous stream of public consumption has to be financed. The Ramsey planner controls consumption, labor and capital taxes, in addition to the nominal interest rate. A similar issue has been studied by Chamley (1981,1986), Chari et al (1994) and Coleman (2000), among others, in standard neoclassical models. They find that optimal policy requires a zero capital tax in the long run. Coleman (2000), in particular, shows that it is optimal to tax consumption and subsidize labor as long as public expenditures include transfers and the consumption tax base is higher than the labor tax base, which is verified in both the model and the data. Schmitt-Grohe and Uribe (2006) analyze the optimal tax scheme in a model with monopolistic competition, price stickiness and monetary transaction costs, but without consumption taxes. They find that a capital subsidy becomes optimal, and the latter is higher if it is possible to tax monopolistic profits separately from capital income. Optimal tax rates, in particular the capital tax rate, are extremely volatile when the stochastic version of the model is taken into account. Optimal taxation under heterogenous agents was first studied in Judd (1985), where the case in which workers do not hold capital is considered. The optimal capital tax remains zero notwithstanding the possibility to use it to redistribute income. Indeed, taxing capital reduces the long run capital level, depresses real wages and ends up reducing workers' income.

Our main findings are the following. Optimal policy requires complete inflation stabilization independently of the share of RT consumers. Monopolistic competition in the labor market and

the LAMP assumption do not affect the optimal capital tax rate in steady state, which remains negative as in the model with monopolistic competition only in the goods market. The presence of a share of liquidity constrained individuals induces the Ramsey planner to a stronger use of consumption taxes in place of labor taxes. The intuition for this result is that while labor taxes disproportionately hit RT consumers whose sole source of income is labor, consumption taxes allow to indirectly tax profits and capital incomes, which only accrue to Ricardian agents. As the latter own the whole wealth of the economy and earn higher incomes, consumption taxes serve the purpose of redistribution which is valuable under a utilitarian Ramsey planner, when the utility function is concave. The consumption tax does not distort the consumption-investment decision in the steady state and is less distortionary.¹

Along the dynamics, the presence of RT consumers calls for stronger responses of debt to shocks and the use of fiscal policy to smooth consumption. We consider the response of the economy following a productivity shock. Productivity shocks increase overall income, but redistribute it from RT consumers to ricardian agents, making the former relatively worse off. Fluctuations in income distribution along the business cycle are inefficient as under full asset market participation and complete markets all idiosyncratic risks would be insured away and the marginal utility ratio between agents would be kept constant. Such inefficiency is the composition of two different effects. First of all, price stickiness tends to cause increases in the mark up of prices over marginal costs, which pushes up monopolistic profits and reduces demand for labor and capital. This can be cured with monetary policy. On the other hand, the fact that all wealth is in the hands of asset market participants (ricardian agents, henceforth) implies that the increase in the return to capital that follows productivity shock is completely appropriated by them, which tends to augment the ratio between the income of the wealthiest agents and that of the poorest. Such an effect can not be confronted by monetary policy, which, on the contrary, tends to increase it by stimulating demand for capital through price stabilization. Fiscal policy can instead play a role. The planner temporarily borrows funds from ricardian agents to finance a reduction of the labor tax. This allows to sustain the consumption of RT consumers and stabilize the marginal utility ratio.

The welfare gains from such a policy critically depend on the curvature of the utility function. The more concave the utility function is, the higher are the costs of income inequality in the steady state and the higher are the costs of its fluctuations along the business cycle. The optimal policy almost eliminates swings in the distribution of income for a KPR utility function with the curvature parameter set at five. In the log-utility case instead, income distribution is not completely stabilised. These differences are stronger when the planner has access to fiscal instruments, as the effectiveness of monetary policy on income distribution is more limited.

The rest of the paper is organized as follows. In section 2 we present the model and the Ramsey problem. Section 3 presents the calibration of the deep parameters of the model. Sections 4 and 5 discuss respectively the optimal deterministic steady state and the optimal Ramsey dynamics. Section 6 contains a welfare analysis and section 7 concludes.

2 The Model

The model we consider is a standard DSGE model augmented with limited asset market participation. It features sticky prices and wages and capital adjustment costs. The government finances

¹A constant consumption tax weighs in the same manner on present and future consumption and does not change the private sector intertemporal consumption allocation. Consumption taxes allow to tax capital and profit income without the intertemporal inefficiencies generated by capital taxes.

an exogenous stream of public consumption by levying labor and capital income taxes along with consumption taxes. Moreover, it sets the nominal interest rate. Monetary and fiscal policies are optimised, in the sense that they are chosen to maximise an utilitarian social welfare function under the constraints given by the competitive equilibrium conditions.

In particular, we assume that the planner has to respect a promise made in an indefinite period in the past. In other words we compute the Ramsey optimal policy under commitment. As is well known, the Ramsey problem is non-stationary in the sense that the planner's first order conditions at time zero are different from the first order conditions at times $t > 0$. The optimization from a timeless perspective amounts to assuming that the initial commitment was made in the past and looks at the asymptotic behaviour of the economy under Ramsey optimal policy. In technical terms this is equivalent to considering the past Lagrange multipliers of the Ramsey program as additional state variables, and setting their value at time -1 to their corresponding steady state value.

2.1 Households

There are two types of households. Ricardian households can freely participate to financial markets and save and consume optimally. On the contrary, RT households are constrained to consume their current labor income and cannot optimize. The utility function is of the KPR type:

$$U(c_t^i, n_t^i) = \frac{1}{1-\sigma} \left(c_t^i \left(1 - \theta n_t^{i\phi} \right) \right)^{1-\sigma} \quad (1)$$

Notice that when $\sigma = 1$ the latter expression collapses to a standard log-utility format: $U(c_t^i, n_t^i) = \ln c_t^i + \ln \left(1 - \theta n_t^{i\phi} \right)$.

2.2 Ricardian Households

The problem for the representative ricardian household, indexed by o , is:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t U(c_t^o, n_t) \quad (2)$$

$$st \quad (1 + \tau_{c,t})c_t^o + b_t^o \leq (1 - \tau_{n,t})w_t n_t + \frac{b_{t-1}^o i_{t-1}}{\pi_t} + d_t^o - \frac{X}{2} \left(\frac{w_t \pi_t}{w_{t-1}} - 1 \right)^2 n_t$$

Ricardian households earn after tax labor income $((1 - \tau_{n,t})w_t n_t)$ and dividends d_t^o and receive payments on past investment in government debt $\frac{b_{t-1}^o i_{t-1}}{\pi_t}$. They buy an amount of the consumption good equal c_t^o after paying $\tau_{c,t}c_t^o$ in consumption taxes and government debt b_t^o . Notice that there is a quadratic cost of adjusting nominal wages.

Ricardian households do not invest directly in capital. Investment in capital is carried out at the level of the intermediate firms. Hence dividends contain both extra-profits deriving from monopolistic competition and the normal return on capital. Moreover, the choice of the labor effort is left to labor unions.

The first order conditions of the problem are:

$$\lambda_t^o (1 + \tau_{c,t}) = (c_t^o)^{-\sigma} \left(1 - \theta n_t^{\phi} \right)^{1-\sigma} \quad (3)$$

$$\frac{1}{i_t} = \beta E_t \left(\frac{\lambda_{t+1}^o}{\lambda_t^o} \frac{1}{\pi_{t+1}} \right) \quad (4)$$

$$(1 + \tau_{c,t}) c_t^o + \frac{b_t}{1 - \psi} = (1 - \tau_{n,t}) w_t n_t + \frac{b_{t-1} i_{t-1}}{(1 - \psi) \pi_t} + \frac{d_t}{1 - \psi} - \frac{X}{2} \left(\frac{w_t \pi_t}{w_{t-1}} - 1 \right)^2 n_t \quad (5)$$

where ψ is the share of RT consumers in the population and π_t is consumer price inflation.

2.2.1 RT Households

RT households do not optimize and simply consume their after tax labor income each period:

$$(1 + \tau_{c,t}) c_t^{rt} = (1 - \tau_{n,t}) w_t n_t - \frac{X}{2} \left(\frac{w_t \pi_t}{w_{t-1}} - 1 \right)^2 n_t \quad (6)$$

The subscript RT indicates that the variables concern a representative RT household. For later use, it is useful to derive the marginal utility of consumption for RT households:

$$\lambda_t^{rt} (1 + \tau_{c,t}) = (c_t^{rt})^{-\sigma} \left(1 - \theta n_t^\phi \right)^{1-\sigma} \quad (7)$$

2.3 Aggregation among households

Average marginal utility and aggregate consumption respectively are:

$$\lambda_t = \psi \lambda_t^o + (1 - \psi) \lambda_t^{rt} \quad (8)$$

$$c_t = (1 - \psi) c_t^o + \psi c_t^{rt} \quad (9)$$

2.4 Unions

The labor market is characterized by a continuum of differentiated labor inputs on the interval (0,1). As standard under the Dixit-Stiglitz model of monopolistic competition, demand for the differentiated labor of type h is given by $l_{ht} = \left(\frac{w_{h,t}}{w_t} \right)^{-\nu} n_t^d$, where n_t^d is total labour demanded by firms and $W_{h,t}$ is the wage for labour type h. Since we assume that each household supplies all types of labour, the amount of hours worked by household i is given by $n_t^i = \int_0^1 \left(\frac{w_{h,t}}{w_t} \right)^{-\nu} dh n_t^d$. This is the labour time that appears in the utility functions of the agents and that the unions consider when solving their problem. Hence, the labor income appearing in the budget constraint of the two representative households is $w_t n_t = \int_0^1 w_{h,t} \left(\frac{w_{h,t}}{w_t} \right)^{-\nu} dh n_t^d$, where $w_t = \left(\int_0^1 w_{h,t}^{1-\nu} dh \right)^{\frac{1}{1-\nu}}$ is the wage index.

The labor market is monopolistically competitive in the sense that there is only one union for each labor type h. Each union solves the following problem:

$$\max E_0 \Sigma_{t=0}^{\infty} \beta^t ((1 - \psi)U(c_t^o, n_t(w_{h,t})) + \psi U(c_t^{rt}, n_t(w_{h,t})))$$

$$\begin{aligned} s.t. \quad (1 + \tau_{c,t})c_t^o + \frac{b_t}{1 - \psi} &= (1 - \tau_{n,t}) \int_0^1 w_{h,t} \left(\frac{w_{h,t}}{w_t} \right)^{-\nu} dh n_t^d + \frac{d_t}{1 - \psi} - \frac{X}{2} \left(\frac{w_{h,t}\pi_t}{w_{h,t-1}} - 1 \right)^2 n_t \\ (1 + \tau_{c,t})c_t^{rt} &= (1 - \tau_{n,t}) \int_0^1 w_{h,t} \left(\frac{w_{h,t}}{w_t} \right)^{-\nu} dh n_t^d - \frac{X}{2} \left(\frac{w_{h,t}\pi_t}{w_{h,t-1}} - 1 \right)^2 n_t^d \end{aligned}$$

The first order condition after aggregating among all unions and considering that all fix the same wage, is the following:

$$\begin{aligned} -\frac{\psi U_n(c_t^o, n_t) + (1 - \psi)U_n(c_t^{rt}, n_t)}{\lambda_t} &= \frac{\nu - 1}{\nu} (1 - \tau_{n,t}) w_t + \frac{X}{\nu} (\pi_{W,t}\pi_t - 1)\pi_{W,t}\pi_t \\ -\beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{X}{\nu} (\pi_{W,t+1}\pi_{t+1} - 1)\pi_{W,t+1}\pi_{t+1} \frac{n_{t+1}}{n_t} \right] & \end{aligned} \quad (10)$$

where

$$U_n(c_t^o, n_t) = - \left(1 - \theta n_t^\phi \right)^{-\sigma} (c_t^o)^{1-\sigma} \theta \phi n_t^{\phi-1} \quad (11)$$

$U_n(c_t^{rt}, n_t)$ is defined analogously, while $\pi_{W,t}$ is real wage inflation, that is $\frac{w_t}{w_{t-1}}$.

2.5 Firms

The goods market is characterized by monopolistic competition of the Dixit-Stiglitz type. Firms produce differentiated goods z in the interval $(0,1)$, which are then aggregated² in the consumption bundle consumed by households.

Firm producing good z maximises profits under a Cobb-Douglas production function and a downward sloping demand function. It also invests, accumulates capital and is subject to a capital adjustment cost and to a quadratic price adjustment cost. The government levies corporate taxes whose tax base is firm profit before investment. Hence, reinvested earnings are not tax deductible.³ The problem is the following:

$$\begin{aligned} \max E_0 \Sigma_{t=0}^{\infty} \beta^t \lambda_t^o [d_{Z,t}] \\ s.t. \quad d_{Z,t} \leq (1 - \tau_{K,t}) \left(\frac{P_{Z,t}}{P_t} y_{Z,t} - w_t n_{Z,t}^d - \frac{K}{2} \left(\frac{P_{Z,t}}{P_{Z,t-1}} - 1 \right)^2 y_{Z,t} \right) - inv_{Z,t} \end{aligned}$$

²Such aggregation can be done either by a final good firm or directly by households. Using one device or the other does not affect the properties of the model.

³Allowing for investment tax deductions would make sure that the capital tax does not distort the consumption-investment decision. We assume the absence of investment allowances to keep consistency with the literature.

$$y_{z,t} \leq A_t (n_{z,t}^d)^\alpha K_{z,t-1}^{1-\alpha} - fc$$

$$y_{z,t} = \left(\frac{P_{z,t}}{P_t} \right)^{-\mu} y_t$$

$$k_{z,t} \leq (1 - \delta) k_{z,t-1} + \omega(\text{inv}_{z,t}, k_{z,t-1}) k_{z,t-1}$$

where $K_{z,t}$ is capital owned by firm z and $\omega(\text{inv}_{z,t}, k_{z,t-1}) = \frac{a_1}{1 - \frac{1}{X^K}} \left(\frac{\text{inv}_{z,t}}{k_{z,t-1}} \right)^{1 - \frac{1}{X^K}} + a_2$ is the capital adjustment cost, which follows the specification in Jermann (1998) and Uhlig (2007). In this formulation, X^K represents the elasticity of the investment to capital ratio with respect to Tobin's Q : the capital adjustment cost is a decreasing function of X^K .

Notice that the discount factor used by firms is obtained from the marginal utilities of ricardian households since firms are owned by them. After aggregating among firms and noticing that all of them fix the same price, the first order conditions for the representative firm are:

$$w_t (1 - \tau_{K,t}) = mc_t A_t \alpha n_t^{\alpha-1} k_{t-1}^{1-\alpha} \quad (12)$$

$$q_t = \frac{1}{\left(a_1 \left(\frac{\text{inv}_t}{k_{t-1}} \right)^{-\frac{1}{X^K}} \right)} \quad (13)$$

$$q_t = E_t \left\{ \beta \frac{\lambda_{t+1}^o}{\lambda_t^o} \left(mc_{t+1} A_{t+1} (1 - \alpha) n_{t+1}^\alpha k_t^{-\alpha} + q_{t+1} [1 - \delta + \left(\left(\frac{1}{1 - \frac{1}{X^K}} - 1 \right) a_1 \left(\frac{\text{inv}_{z,t+1}}{k_t} \right)^{1 - \frac{1}{X^K}} + a_2 \right)] \right) \right\} \quad (14)$$

$$mc_t = (1 - \tau_{k,t}) \left[\frac{\mu - 1}{\mu} + \frac{K}{\mu_t} (\pi_t - 1) \pi_t - \beta E_t \left[\frac{\lambda_{t+1}^o}{\lambda_t^o} \frac{K}{\mu_t} (\pi_{t+1} - 1) \pi_{t+1} \frac{y_{t+1}}{y_t} \right] \right] \quad (15)$$

$$y_t = A_t n_t^\alpha k_{t-1}^{1-\alpha} - fc \quad (16)$$

$$k_t = (1 - \delta) k_{t-1} + \omega(\text{inv}_t, k_{t-1}) k_{t-1} \quad (17)$$

$$d_t = (1 - \tau_{k,t}) \left(y_t - w_t n_t - \frac{K}{2} (\pi_t - 1)^2 y_t \right) - \text{inv}_t \quad (18)$$

where mc_t are real marginal costs, q_t is Tobin's Q and π_t is the price index inflation. A_t is the technology variable and follows a AR(1) process of the form $\log A_t = \rho_A \log A_{t-1} + \varepsilon_{A,t}$, with $\varepsilon_{A,t}$ distributed as a i.i.d. $n(0, \sigma_A^2)$.

2.6 Government Budget Constraint

The government budget constraint is as follows:

$$b_t + \tau_{c,t} c_t + \tau_{k,t} \left(y_t - w_t n_t - \frac{K}{2} (\pi_t - 1)^2 y_t \right) + \tau_{n,t} w_t n_t = g_t + \frac{b_{t-1} i_{t-1}}{\pi_t} \quad (19)$$

where g_t is real public consumption, which is exogenously given, and b_t is the real public debt outstanding.

2.7 Ramsey Planner

Define the vector of variables $x_t = [\lambda_t^o \ c_t^o \ b_t \ c_t^{rt} \ \lambda_t^{rt} \ c_t \ \lambda_t \ n_t \ w_t \ q_t \ inv_t \ mc_t \ y_t \ k_t \ d_t \ \pi_t]$. The competitive equilibrium of the model economy is defined as the sequence of private sector decisions $\{x\}_{t=0}^\infty$ that satisfy equations (3)-(19) and the relevant transversality conditions, taking as given the policy sequences $\{\tau_k\}_{t=0}^\infty$, $\{\tau_n\}_{t=0}^\infty$, $\{\tau_c\}_{t=0}^\infty$ and $\{i\}_{t=0}^\infty$ and the exogenous processes $\{A\}_{t=0}^\infty$ and $\{g\}_{t=0}^\infty$. There will be a continuum of competitive equilibria indexed by the sequences $\{\tau_k\}_{t=0}^\infty$, $\{\tau_n\}_{t=0}^\infty$, $\{\tau_c\}_{t=0}^\infty$ and $\{i\}_{t=0}^\infty$. The Ramsey planner solution is a competitive equilibrium in which the sequences $\{\tau_k\}_{t=0}^\infty$, $\{\tau_n\}_{t=0}^\infty$, $\{\tau_c\}_{t=0}^\infty$ and $\{i\}_{t=0}^\infty$ are chosen in order to maximise the following social welfare function:

$$V = E_0 \sum_{t=0}^{\infty} \beta^t [(1 - \psi) U(c_t^o, n_t) + \psi U(c_t^{rt}, n_t)] \quad (20)$$

As already mentioned, we look at the asymptotic behaviour of the economy under Ramsey optimal policy, as is standard in the literature (see Schmitt-Grohe and Uribe, 2004). We solve for the planner first order conditions using Matlab and use our version of the OLS approach proposed in Schmitt-Grohe and Uribe (2011) to solve for the steady state. The dynamics around the steady state is computed using Dynare.

3 Calibration

The time unit is meant to be a quarter. The calibration of the deep parameters of the model is consistent with the literature. We calibrate the discount factor β to 1/1.01, the steady state mark-ups to 0.2, by setting $\mu = \nu = 6$, quarterly capital depreciation δ to 0.025 and the Rotemberg parameters for price and wage stickiness to 76, such that if a Calvo model was used instead,⁴ nominal prices would be readjusted every 4.5 quarters. Such frequencies are not far from estimates in the literature, see Colciago (2011) and Smets and Wouters (2007). We set the share of labour in the production function α to 70%, as in Schmitt-Grohe and Uribe (2006). We calibrate $\theta = 0.5307$ such that under an efficient steady state, hours worked would be equal to one.⁵ ϕ is set such that the Frisch elasticity is about 1.3,⁶ which is in line with macro estimates (see for instance Fiorito and Zanella, 2012). The calibration of X^K follows De Graeve et al (2010) who set it equal to 0.5. As in Christiano et al (2005), fixed cost fc represents the 20% of steady state output, such that economic profits in steady state are zero. The share of RT consumers is 40%, within the range estimated in the literature reported in the introduction. We consider two different initial levels for public debt: in the first we set it to zero and in the second we set it equal to the 44% of yearly GDP as in Schmitt-Grohe and Uribe (2004). The share of steady state government consumption over

⁴Keen and Wang (2007) show how to convert a Calvo parameter into a Rotemberg parameter.

⁵We get this result by calculating the steady state of a social planner problem and finding the value of θ that guarantees $N = 1$.

⁶Notice that under the functional form considered in the paper the Frisch elasticity is $\frac{1}{\phi \left(1 + \frac{\theta N_{ss}^\phi}{1 - \theta N_{ss}^\phi}\right) - 1}$. The

Frisch elasticity depends on steady state hours worked. For this reason, changing the parametrization of the model affects the Frisch elasticity even if ϕ is kept constant. Nevertheless, the Frisch elasticity never changes drastically in the latter case.

GDP is calibrated to 0.19, consistently with US data. The standard deviation of the productivity shock σ_A is set to 0.01 and its persistence ρ_A to 0.95 as in De Paoli et al (2010).

We consider different values for the coefficient σ , which governs the curvature of the utility function with respect to consumption and the degree of non separability between hours worked and consumption. This coefficient is very important as the more concave is the utility function the stronger is the planner's desire to redistribute income. In particular, we consider two calibrations of σ . In the baseline model we set it to one: this corresponds to the log-utility case with utility function separability. When analysing the implications of the availability of fiscal tools for the optimal redistributive policy along the business cycle we consider also a value of σ equal to 5. This value is often used in the macro-finance literature (see De Paoli et al, 2010).

4 Ramsey Steady State

Table 1 reports the values of some variables of interest in the Ramsey steady state compared to the values under the efficient steady state,⁷ under LAMP and under the representative agent model.

	Social Planner	Ramsey Planner $\psi = 0.4$		Ramsey Planner $\psi = 0$	
		$\frac{b}{4y} = 0.44$	$\frac{b}{4y} = 0$	$\frac{b}{4y} = 0.44$	$\frac{b}{4y} = 0$
n	1	0.78	0.79	0.76	0.77
k	21.5245	14.84	15.26	14.5	14.74
y	2.0927	1.57	1.61	1.54	1.56
c	1.5545	0.90	0.92	0.88	0.90
c^o	1.5545	1.01	1	-	-
c^{rt}	1.5545	0.75	0.79	-	-
w	-	1.41	1.42	1.41	1.41
π	-	1	1	1	1
τ_k	-	-0.1	-0.109	-0.1	-0.101
τ_n	-	0.208	0.16	0.29	0.307
τ_c	-	0.16	0.19	0.06	0.01

Table 1: Deterministic steady state results

The steady state of the competitive economy presents several distortions. First of all, the economy features monopolistic competition in the goods and labor markets, which generates inefficient rents and reduces the amount of labor employed and of goods produced with respect to the first best. Price and nominal wage adjustment costs imply that price and wage changes destroy real resources. Limited asset market participation generates wealth and consumption inequality which the planner dislikes, due to utility function concavity. Lastly, the Ramsey planner is obliged to finance an exogenous stream of public consumption which is pure waste, since it enters neither the utility function of agents nor the production function of firms, and has to do it by levying distortionary taxation, as a technology to collect lump-sum taxes is not available by assumption.

In a cashless model like the one analyzed here, the optimal rate of inflation is zero. As is well known, in fact, in this kind of model the trade off between using inflation to reduce the monopolistic

⁷The efficient steady state is obtained by solving the social planner problem, which consists in maximising over an infinite horizon the social welfare function under the production function, the aggregate resource constraint and the capital accumulation equation. The results of the latter problem are well known. See for instance Motta and Tirelli (2012).

power of firms and setting it to zero to eliminate price adjustment costs is resolved in favor of the latter (see for instance Kahn et al, 2003). Such a result is not affected by the introduction of LAMP. It is instead interesting to observe how the optimal steady state tax rates are affected by LAMP. While capital is subsidized both under LAMP and under the representative agent model, in the latter case the Ramsey planner almost does not make use of the consumption tax, while consumption taxes are much higher under LAMP.

The result concerning the representative agent model is somewhat surprising, as a long stream of literature (see for instance Coleman, 2000) has shown the optimality of consumption taxes in representative agent models. In separate experiments, we verified that the preference for the labor tax is not due to monopolistic competition in the goods or labor market, but to the presence of fixed production costs. The result in Coleman (2000) depends on the fact that the consumption tax base is bigger than the labor tax base. This makes sure that a relatively lower consumption tax rate allows to generate relatively bigger revenues and the distorsive effect of consumption taxes on labor supply can be compensated by appropriate labor subsidies. When fixed costs are present, labor supply must increase to generate the additional resources necessary to pay for them. The labor tax base gets bigger, which implies that a lower labor tax rate generates more revenues. As a consequence, relying on labor taxes rather than on consumption taxes to pay for government outlays becomes more convenient.

Introducing LAMP in the model tends to increase, *coeteris paribus*, hours worked, capital and output. Any dispersion in the marginal utility of consumption of the two agents induces unions to increase the supply of labor for any wage level. In fact, due to the concavity of the utility function, the wealth effect on labor supply depends more on the consumption of the poorest than on the consumption of the wealthiest. The increase in labor supply augments the productivity of capital, stimulates its accumulation and increases output. Under LAMP consumption taxes are always larger and labor taxes always smaller than under the representative agent model. Indeed, consumption taxes allow to tax capital income indirectly, without affecting the intertemporal consumption-investment decision of ricardian households. Taxing capital income, even though indirectly, allows the planner to redistribute income from ricardian to RT households.⁸ Using capital income taxes to redistribute is instead very inefficient, since it lowers the long run capital level, with obvious negative effects on real wages and RT agents income. The subsidy on capital is indeed almost unaffected by LAMP.

Steady state public debt reduces output and consumption because it requires higher distortionary taxes. A positive public debt level redistributes income from RT agents to ricardian agents since the latter are the sole buyers of government bonds. This makes sure that the reliance on consumption taxes becomes bigger when public debt is positive. Nothing similar happens under the representative agent model in which no inequality concern is at work.

5 Ramsey Dynamics

In this section, we present the optimal dynamics of the economy. First we compute optimal second moments, then we discuss impulse response functions to a productivity shock.

⁸Notice that our model is different from Guo and Lansing (1999) who show that the optimal capital tax rate under monopolistic competition in the goods market can be positive or negative depending on the parameterization. We do not include depreciation allowances, which would tend to increase the optimal capital tax rate. Moreover, fixed production costs eliminate monopolistic profits in the steady state. The absence of the profit effect eliminates the most important incentive for a higher capital tax rate.

5.1 Moments

Since our model solution features a unit root, theoretical unconditional moments do not exist and variables may wander far away from the steady state in the long run. As a consequence, local approximations behave very poorly the longer is the simulation length. On the other hand, our model contains too many state variables for global solution methods to be employed. We adopt the procedure described in Schmitt-Grohe and Uribe (2004): we compute J simulations of length T periods and take the arithmetic average of the moments. Schmitt-Grohe and Uribe (2004) show in a simpler model that a first order approximation is good as long as the simulation period is not very long and set $J=500$ and $T=100$. We adopt the same values.

	$\psi = 0.4$				$\psi = 0$			
	$\frac{b}{4y} = 0$		$\frac{b}{4y} = 0.44$		$\frac{b}{4y} = 0$		$\frac{b}{4y} = 0.44$	
	<i>stdev</i>	<i>Autcor</i>	<i>stdev</i>	<i>Autcor</i>	<i>Stdev</i>	<i>Autcor</i>	<i>Stdev</i>	<i>Autcor</i>
<i>n</i>	0.02	0.2456	0.0215	0.2134	0.0109	0.1301	0.0087	0.0734
<i>inv</i>	0.0134	0.5121	0.0095	0.7748	0.0098	0.5648	0.0065	0.8621
<i>y</i>	0.0595	0.4721	0.0602	0.4285	0.0446	0.5396	0.0396	0.5344
<i>c</i>	0.0461	0.4621	0.1357	0.3518	0.0349	0.5338	0.0356	0.4093
<i>c_O</i>	0.0588	1	0.0687	0.3775	-	-	-	-
<i>c_{RT}</i>	0.0293	0.5122	0.029	0.3262	-	-	-	-
<i>i</i>	0.0212	0.3264	0.0148	-0.2745	0.016	0.1051	0.0202	-0.1523
π	0	0.9361	0	0.8712	0	0.9096	0	0.9256
τ_k	0.6442	0.2385	0.7026	0.1366	0.4226	0.2123	0.4741	0.1010
τ_n	0.1374	0.9475	0.0987	0.9482	0.0953	0.8766	0.1101	0.3878
τ_c	0.1837	0.9432	0.1357	0.9213	0.121	0.9337	0.0984	0.888
<i>b</i>	1.6101	0.9737	1.5159	0.9668	1.0684	0.9822	1.0820	0.9793

Table 2: Optimal second order moments.

Optimal inflation volatility is almost equal to zero under LAMP as well as under the representative agent model. This result is standard: optimal monetary policy is not influenced by the RT hypothesis. The overall volatility of the economy (see for instance output, consumption and investment) is higher under LAMP than under the representative agent model. This at least partially depends on the different characteristics of fiscal policy under the two models. Under LAMP all tax rates are more volatile; moreover the standard deviation of the consumption of Ricardian agents is much higher than that of RT consumers and than that of the representative agent in the model with $\psi = 0$. Such results suggest that the Ramsey planner is willing to accept a higher volatility of the overall economy in order to make RT consumers better off. The analysis delivered in the next sections helps to understand this point.

5.2 Impulse Responses

The impulse response functions to a positive productivity shock under LAMP and under the representative agent model are in Figures 1 and 2. To sharpen the analysis and enhance intuition, we assume that public debt is zero in steady state and that the productivity shock is not autocorrelated.

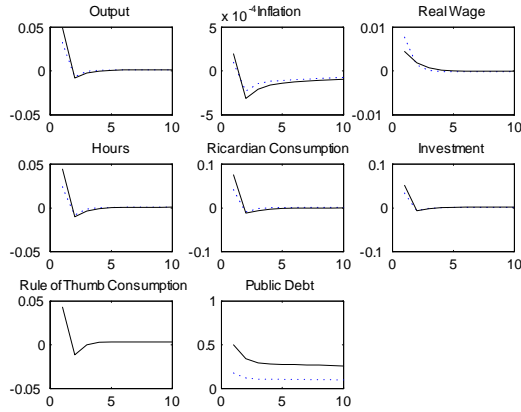


Figure 1 - Impulse responses to a one standard deviation productivity shock. Full line: LAMP model. Dotted line: representative agent model. All responses, apart from public debt, are in percentage points deviations from the steady state. Public debt is reported as deviation from the steady state in levels.

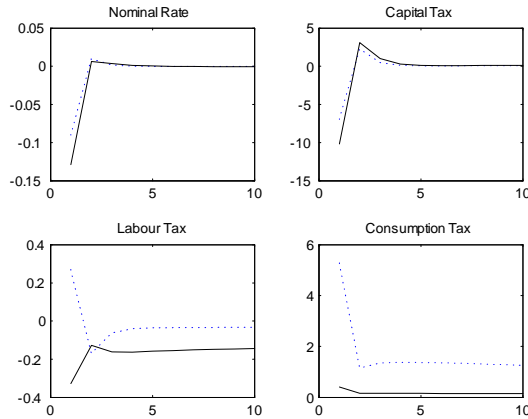


Figure 2 - Impulse responses to a one standard deviation productivity shock. Full line: LAMP model. Dotted line: representative agent model. All responses are in percentage points deviations from the steady state.

The optimal responses of the Ramsey planner under LAMP and under the representative agent model share some common properties. Inflation is almost completely stabilised, nominal rates are lowered and the subsidy on capital is highly volatile. These results are well known. It is in fact optimal to stabilise firm mark-ups by using monetary policy and to tax (or subsidise) more strongly production factors which are in fixed supply or predetermined, as is capital in this model.

Under the representative agent model, consumption taxes and labor taxes are strongly increased at impact. This behaviour can be rationalized if wage stickiness is taken into consideration. Under the first best, hours worked would fall slightly as the wealth effect overcomes the substitution effect.⁹

⁹Agents' income goes up by more of the real wage, because of increased capital income.

Under a competitive economy with nominal rigidities, managing the nominal interest rate allows to stabilise firms' mark up but not necessarily the mark up of wages over the marginal rate of substitution. In particular, once the Ramsey planner stabilises inflation by stimulating aggregate demand through interest rate cuts, she tends to drive hours worked above the efficient level. Wage stickiness, in fact, reduces the leftward shift of the wage setting schedule, which implies that real wages grow less and hours more than under the first best. As a consequence, the wage mark up over the marginal rate of substitution decreases. The scope of the higher consumption and labor taxes is to increase the tax wedge on labor, disincentivating excessive labor supply.

Under LAMP the consumption tax is much more stable, the labor tax falls and the nominal rate goes down more strongly. Moreover public debt is increased by more. Output, consumption, investment and hours respond more strongly than under the representative agent model. The Ramsey planner wants to offset the large fluctuations in the consumption ratios of the two agents provoked by productivity shocks. In the absence of targeted transfers, the planner can provide relief to RT consumers by stimulating aggregate demand and adjusting tax rates to put the major fiscal burden on ricardian households. A higher aggregate demand increases the demand for labor, which in turn increases RT income. This objective is pursued through the stronger interest rate cuts and the lower response of the consumption tax. Moreover the labor tax is reduced, differently from the representative agent model. Such a measure constitutes a strong subsidy to RT agents' income. The optimal policy implies a higher government deficit and a stronger stimulus under LAMP.

5.3 Optimal Fiscal Policy as a Device to Smooth Income Distribution Fluctuations

While steady state analysis allows to understand how taxation is implemented to redistribute income and reduce inequality; the analysis of the dynamics of the model economy allows to gather intuition on how the Ramsey planner can use fiscal policy to reduce fluctuations in income distribution. When shocks are symmetric and the Ramsey planner response to them is also constrained to be symmetric,¹⁰ in fact, the best achievable result is that of a complete elimination of all idiosyncratic risks. That is exactly what agents would do if both ricardians and RT consumers were allowed to invest in contingent securities. In our case, the productivity shock is symmetric by assumption. Moreover, we solve the model using first order perturbation methods which eliminate any possibility of an asymmetric response of the Ramsey planner to shocks. Employing a higher order perturbation approach would in principle allow to consider non symmetric responses to shocks. However, for perturbation methods to be accurate, shocks must be small and in this case the non-linearities which are present in the model are unlikely to produce significant asymmetric responses on the part of the planner. Our objective is to check if using fiscal tools can enhance substantially the ability of the Ramsey planner to reduce fluctuations in income distribution, which are more difficult to control using only monetary instruments.

In order to analyse this question, we first define the ratio between the marginal utility of consumption of the two agents: $R = \left(\frac{c_t^o}{c_t^r}\right)^{-\sigma}$. R is always equal to one under the first best and its standard deviation is zero. Then we compare the impulse response function of R in the Ramsey model with fiscal instruments to the impulse response function of R under a Ramsey model in which the planner can only move the nominal interest rate and under a model in which monetary policy is conducted through a simple Taylor rule with coefficient 1.5 on inflation. To make the

¹⁰As we are going to make clear later, this is our case.

results comparable, we assume that under all three models steady state public expenditure is zero. A positive level of steady state public consumption would entail the use either of non distortionary taxation or of simple fiscal rules in the models where the planner can not optimize with respect to fiscal instruments, which would make the comparison of the results of the three models less intuitive. For the sake of illustration, we consider two values for σ : in Figure 3 σ equals one and in Figure 4 it equals five.

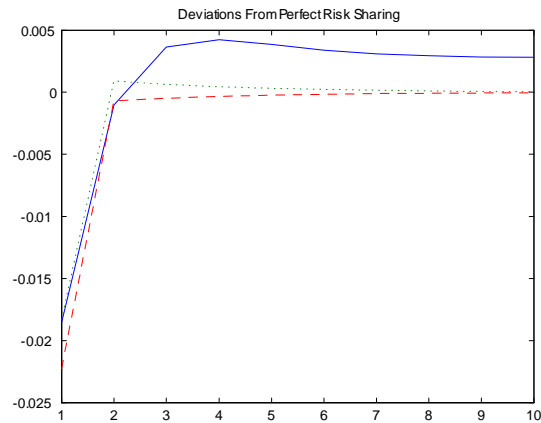


Figure 3 - Impulse response of R to a one standard deviation productivity shock with $\sigma = 1$. —: Ramsey with fiscal instruments. ···: Ramsey without fiscal instruments. - - -: Taylor rule. The response is in percentage points deviation from the steady state.

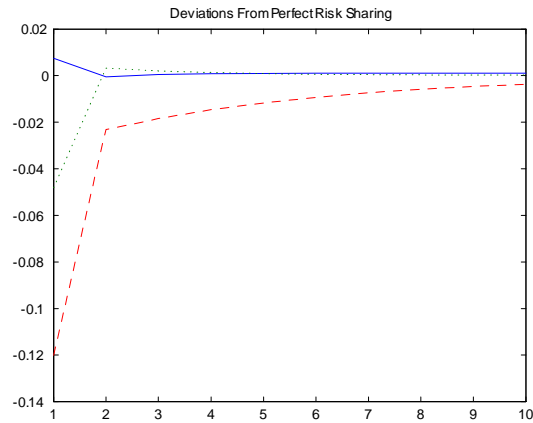


Figure 4 - Impulse response of R to a one standard deviation productivity shock with $\sigma = 5$. —: Ramsey with fiscal instruments. ···: Ramsey without fiscal instruments. - - -: Taylor rule. The response is in percentage points deviation from the steady state.

Differences in the responses of R between the case in which the planner can use fiscal instruments and the case in which it can not, critically depends on the concavity of the utility function. When

$\sigma = 1$, the response of fiscal policy, even if very strong as underlined in the previous section, does not seem to entail important differences in the fluctuations of the ratio of agents' marginal utilities. Indeed, a relatively low curvature of the utility function implies that fluctuations in consumption and in the distribution of income over time are not very costly. In this case, indeed, fiscal instruments do not reduce very much the fall of R following a productivity shock. With $\sigma = 5$ instead fiscal policy is used to stabilise income distribution. Indeed, there is a slight increase in R following the shock. With a relatively high curvature of the utility function, fluctuations in the distribution of income are very costly and the role of fiscal policy becomes more important.¹¹

Monetary policy is less effective than fiscal policy in reducing fluctuations in income distribution because it has two effects that work in opposite directions. On the one hand monetary policy can close the marginal cost gap and eliminate fluctuations in mark ups and extra-profits. This tends to reduce the surge of inequality produced by productivity shocks. But closing the marginal cost gap also stimulates the demand for production factors, and while the higher demand for labor increases labor income for both agents, the higher demand for capital only benefits ricardians. This implies that ricardian agents income is pushed up more than that of RT consumers and monetary policy can not do anything to reduce the increase in inequality that follows. Here is where fiscal policy plays its role. By borrowing funds from ricardian agents to subsidize labor, the Ramsey planner is able to reduce the gap between the consumption of the two agents. In the case of a negative productivity shock instead, the Ramsey planner taxes labor to lend the revenues to Ricardians, again reducing the fluctuation in relative marginal utility.

6 Conclusions

We check if standard results concerning optimal policy in DSGE models are robust to the introduction of agent heterogeneity in the form of limited asset market participation. We analyze the issue in a fully fledged DSGE model with nominal and real rigidities in which the Ramsey planner has access to a wide range of fiscal instruments, besides the nominal interest rate. In particular we assume that the planner can use taxes on labor, consumption and capital.

We find that monetary policy maintains the role of completely stabilizing inflation, but is not very useful in tackling the inefficiencies linked to LAMP. In particular, it is unable to tackle inequality in steady state and has limited traction in reducing swings in income distribution. Fiscal policy can instead play its role both in the steady state, reducing inefficiencies due to monopolistic competition and inequality, and along the business cycle, attenuating the fluctuations in income distribution. These objectives are not reached by using capital taxation. Indeed we confirm the standard results of optimal taxation in representative agent models that capital should not be taxed and it should be subsidized in the presence of monopolistic competition. Taxing capital to redistribute income is particularly inefficient, because it depresses the long-run capital level reducing labor productivity and wages, with negative consequences also for RT consumers. Redistribution is better complied with by a stronger use of consumption taxation in place of labor taxation.

Along the business cycle, LAMP implies that it is optimal to let government deficits fluctuate more heavily and to use public debt to attenuate the effect of the productivity shock on income distribution. In particular, following a positive productivity shock it is optimal to cut labor taxes

¹¹Notice that when $\sigma = 5$, the Ramsey planner adopts a more redistributive policy als in the steady state. With $\sigma = 1$ and $g = 0$, in fact, she sets $\tau_n = 0.35$ and $\tau_k = -0.1$ and $\tau_c = -0.28$. With $\sigma = 5$ instead the optimal tax scheme is $\tau_n = 0.05$ and $\tau_k = 0$ and $\tau_c = -0.04$. Along the business cycle, the response of fiscal variables is similar but stronger for relatively high values of σ .

and let public debt increase strongly. Such a policy reaction is totally different from the optimal response under the representative agent model. In that model indeed the labor and the consumption tax rates are strongly increased. The difference in the behaviour of the Ramsey planner is due to the fact that under LAMP the planner wants to reduce fluctuations in income distribution as much as possible. Productivity shocks tend to raise income inequality because they trigger positive responses of profits. Financing a cut of labor taxes through an increase in public debt amounts to subsidise RT consumers' income borrowing funds from ricardian agents. The Ramsey planner uses public debt to balance the effect of the shock on income distribution.

Our results suggest that fiscal activism can be important to reduce steady state inequality and to limit the negative effects of shocks on agents' welfare. Such results can be obtained even in the absence of targeted transfers, by intelligently manipulating consumption and labor tax rates and by letting budget deficits react more strongly to shocks.

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