Monetary Policy, Doubts and Asset Prices

Pierpaolo Benigno[a,], Luigi Paciello[b]

[a] LUISS and EIEF[b] EIEF

November 1, 2011

Abstract

Asset prices and the equity premium might reflect doubts and pessimism. Introducing these features in an otherwise standard New-Keynesian model changes in a quite substantial way the nature of optimal policy. Three are the main results: i) asset-price movements improve the inflation-output trade-off so that average output can rise without increasing much average inflation; ii) a "paternalistic" policymaker –maximizing the expected utility of the consumers under the true probability distribution– chooses a more accommodating policy towards productivity shocks than in a standard New-Keynesian model and inflates the equity premium; iii) a "benevolent" policymaker–maximizing the objective through which decisionmakers act in their ambiguos world–follows a policy of price stability.

1 Introduction

The theme of monetary policy and asset prices has been widely debated in the literature, especially after the 2007-2009 financial crisis. Several authors have argued that monetary policy in the last decade was too expansionary when compared to the previous twenty years, and that a policy more aggressive toward inflation would have been beneficial to avoid the spur of the asset price bubble.[1]

In this paper, we revisit the theme of monetary policy and asset prices in a standard New-Keynesian monetary model. An important shortcoming of current models is to have counterfactual implications for the equity premium and other financial relationships. We address this issue by introducing distortions in agents' beliefs– doubts and ambiguity aversion– which enable the model to reproduce realistic values for the equity premium and the market price of risk.[2]

We are interested in studying how the presence of doubts and ambiguity, and the consequence that premia on risky assets are significant, influence the characterization of optimal monetary policy. In this environment, we distinguish between a "paternalistic" policymaker who cares about the utility of agents evaluated under the true probability distribution, and a "benevolent" policymaker who maximizes the objective through which agents handle their decisions in their ambiguous world. In presence of ambiguity, the policy conclusions change in a substantial and interesting way with respect to the standard model without ambiguity when the policymaker is "paternalistic", while they do not change for the "benevolent" policymaker.

In the benchmark model without ambiguity, discussed in the literature, the welfare-maximizing policy following a productivity shock involves keeping prices stable. Moreover,

[1] See for instance the discussion of Taylor (2007) and section 5 in Greenspan (2010). See also *The Economist* May 18th 2010.

[2] Doubts and aversion to ambiguity are introduced using the framework of Hansen and Sargent (2005, 2007). See Barillas et al. (2009) for the ability of this framework to reproduce realistic values for the equity premium and the price of risk.

average output cannot rise because it is too costly to increase average inflation.[3] In our framework, the welfare-maximizing policy of the "paternalistic" policymaker is more accommodating and involves an increase in inflation following positive productivity shocks. The inflation-output trade-off becomes less severe, because of the interaction between asset prices and firms' price-setting behavior. The equity premium is higher than under a price-stability policy because equity returns are more procyclical. Indeed, average output can rise without much increase in average inflation if the firms' discounted value of current and future costs does not move much. This is the case when future marginal costs are procyclical while the stochastic discount factor is countercyclical, a property which is indeed enhanced by the presence of doubts in the model. Thanks to this flattening of the trade-off between average inflation and average output, a more expansionary policy is optimal because it can correct for the inefficiencies due to monopolistic competition by raising average output while keeping average inflation low.

When the policymaker is instead "benevolent", two forces balance out to deliver price stability as the optimal policy. One pointing towards a more procyclical policy through the channel described above, and the other towards a countercyclical policy because of the way doubts now distort the objective of the policymaker.

We further show that an interest rate rule calibrated to match monetary policy under Greenspan's tenure as a chairman of the Federal Reserve achieves equilibrium allocations that resemble the ones prescribed by optimal policy of the "paternalistic" policymaker in our framework. In addition, we show that Greenspan's policy is closer to optimal policy in our model than the traditional Taylor rule. In fact, in our model, exploiting the less severe output-inflation trade-off requires a relatively more procyclical policy. However, we also find that the estimated Greenspan's policy is too accommodative even from the perspective of our model.

[3] For an overview of the main results of the literature see Benigno and Woodford (2005), Khan, King and Wolman (2003) and the recent review of Woodford (2009b).

The closest paper to our work is Karantounias (2009) which analyzes a Ramsey problem but in the optimal taxation literature where, like in our model, the private sector distrusts the probability distribution of the model while the government fully trusts it. Beside the different focus of the two economic applications, the other subtle difference is in the approximation method. Whereas Karantounias (2009) approximates around the stochastic no-distrust case for small deviations of the parameter identifying the dimension of the set of nearby model, we approximate around a deterministic steady state allowing for even large deviations of the same parameter while bounding the maximum amplitude of the shocks.

Woodford (2009a) studies an optimal monetary policy problem in which the monetary policymaker trusts its own model but not its knowledge of the private agents' beliefs. In our context, it is just the private sector which has doubts on the true model whereas the policymaker is fully knowledgeable also with respect to the doubts of the private sector. Moreover, Woodford (2009a) uses a New-Keynesian model where distorted beliefs are introduced in an already approximated linear-quadratic environment with the consequence that his model cannot be considered as an approximation to a general equilibrium model of optimal monetary policy under distorted beliefs.[4] Both issues explain why in his context, in contrast to our results, the optimal stabilization policy following productivity shocks is to keep prices stable no matter what is the degree of distrust that the agents might have. Dupor (2005) analyzes optimal monetary policy in a New-Keynesian model in which only the investment decisions are distorted by an *ad hoc* irrational expectactional shock. In our framework, the distortions in the beliefs are instead the result of the aversion to model mis-specification on the side of households, which also affects in an important way the intertemporal pricing decisions of the firms on top of the investment decisions.

There are several other papers that have formulated optimal monetary policy in *ad hoc*

[4]Indeed, in his framework distorted beliefs should not appear in a first-order approximation of the AS equation–as it is instead assumed. Moreover, beliefs will affect second-order terms and therefore the construction of the micro-founded quadratic loss function unless the approximation is taken around a non-distorted steady state.

linear-quadratic framework where the other main difference with respect to our work is that the monetary policymaker distrusts the true probability distribution and the private-sector expectations are aligned with that distrust.[5] We, instead, take a pure normative perspective from the point of view of a fully knowledgeable policymaker who knows the true probability distribution and understands that the private sector distrusts it.

The structure of the paper is the following. Section 2 discusses model uncertainty. Section 3 presents the model. Section 4 characterizes the optimal policy. Section 5 studies the mechanism through which doubts and ambiguity matter for policy. Section 6 compares optimal policy with interest-rate rules. Section 7 concludes.

2 A model of doubts and ambiguity

In this section, we describe how we introduce ambiguity and doubts in a standard New-Keynesian model. In particular we borrow the framework from the model of ambiguity developed by Hansen and Sargent (2001, 2005, 2007, 2008).

In this environment, agents are endowed with one model, called the "reference" model, represented by a particular probability distribution. To describe the model, let us consider a generic state of nature s_t at time t and define s^t as the history $s^t \equiv [s_t, s_{t-1}, ..., s_0]$. We denote with $\pi(s^t)$ the "reference" probability measure on histories s^t. The "reference" model is given to the agent as the true probability distribution, but he/she does not trust it. He/She expresses his/her distrust by surrounding the "reference" model with a set of alternative nearby models. At the end, agents act using one of the alternative models, i.e. a nearby "subjective" distribution which is close to the "reference" probability distribution.

A generic nearby "subjective" probability distribution, called $\tilde{\pi}(s^t)$, is such because it is modelled to be absolutely continuous with respect to the "reference" measure.[6] With

[5] See the papers cited in Ellison and Sargent (2009) and among others Dennis et al. (2009), Giannoni (2002), Leitemo and Soderstrom (2008), Rudebusch (2001).

[6] Absolute continuity is obtained by using the Radon-Nykodym derivative, which converts the reference

this property, the "reference" and the "subjective" measures agree on which events have zero probability. Moreover, the ratio between the two probability measures, $\tilde{\pi}(s^t)/\pi(s^t)$, is equivalent to another probability measure $G(s^t)$, which indeed acts as a change of measure and is a non-negative martingale with the property

$$E(G_t) \equiv \sum_{s^t} G(s^t)\pi(s^t) = 1. \tag{1}$$

The martingale increment $g(s_{t+1}|s^t)$, defined as $g(s_{t+1}|s^t) \equiv G(s^{t+1})/G(s^t)$ with $E_t g_{t+1} = 1$, represents instead the change of measure in conditional probabilities and is equivalent to the likelihood ratio $\tilde{\pi}(s_{t+1}|s^t)/\pi(s_{t+1}|s^t)$.

For each random variable X_{t+1}, the martingale G_t and the martingale increment g_{t+1} define the mappings between the unconditional expectations under the two measures and between their conditional expectations, respectively

$$\tilde{E}(X_t) \equiv \sum_{s^t} \tilde{\pi}(s^t)X(s^t) = \sum_{s^t} G(s^t)\pi(s^t)X(s^t) \equiv E(G_t X_t), \tag{2}$$

$$\tilde{E}_t(X_{t+1}) = E_t(g_{t+1}X_{t+1}), \tag{3}$$

where, $E(\cdot)$ and $\tilde{E}(\cdot)$, denote the expectation operators under the "reference" and "subjective" probability measures, and $E_t(\cdot)$ and $\tilde{E}_t(\cdot)$ the respective conditional-expectation operators.

In this environment, decision makers have too choose how to handle model uncertainty and need to make their consumption and leisure decisions. In particular, in the Hansen-Sargent framework, decision makers act using one of the nearby "subjective" probability measure and use this to evaluate the expected discounted value of the utility flows $U(C_t, L_t)$ where C_t is a consumption index, which will be specified later, and L_t is leisure. In particular,

measure into the subjective one. This property prevents mistakes to be detected in finite samples. See Hansen and Sargent (2001, 2005, 2007) for details.

preferences are described using the multiplier-preference approach of Hansen and Sargent (2001, 2005, 2007, 2008) as

$$E_{t_0}\left\{\sum_{t=t_0}^{\infty}\beta^{t-t_0}G_tU(C_t,L_t)\right\}+\kappa\beta E_{t_0}\left\{\sum_{t=t_0}^{\infty}\beta^{t-t_0}G_tE_t(g_{t+1}\ln g_{t+1})\right\}, \tag{4}$$

where β, with $0<\beta<1$, is the intertemporal discount factor. The objective (4) is composed by two terms. The first term represents the expected discounted value of the utility flows from consumption and leisure, where expectations are indeed taken with respect to the distorted probability measure. Agents choose consumption, labor and asset allocations, which will be specified later, to maximize the objective (4) under their budget constraint. The second term, instead, represents discounted entropy which measures the distance between the "reference" and the "subjective" probability distribution. Choices over the distorted beliefs, $\tilde{\pi}(s^t)$, described here by G_t and g_t, are taken by minimizing the objective (4). How much entropy to allow with respect to the "reference" model depends among other things on the parameter κ, with $\kappa>0$, which is indeed a penalty parameter capturing the degree of ambiguity that the agent faces.[7] Higher values of κ imply less fear of model mis-specification, because this raises the cost of entropy in the minimization problem implying a choice for a less distorted probability distribution. When κ goes to infinity the optimal level of entropy that minimizes (4) is zero. Therefore choices are made under rational expectations, since $g_t=1$ at all times.

Therefore, according to (4), agents' decision problem in this economy is, on the one side, "standard", since they will choose consumption and leisure to maximize expected discounted utility, where however expectations are taken with respect to the distorted measure. On the other side, the non-standard feature is that they will also make decisions with respect to

[7] Hansen and Sargent (2001, 2005, 2007, 2008) show that the preference specification given by (4) can be mapped into a different problem in which entropy is treated directly as a constraint on the set of alternative models that the agent can consider. In particular they relate the parameter κ to the Lagrange multiplier of the entropy constraint in this alternative environment. They also show that the two models can be aligned to imply the same equilibrium outcome.

which distorted probability measure to use. This choice corresponds to the most unfavorable one given the weight entropy has in their preferences.

Hansen and Sargent (2001, 2005, 2007, 2008) show that the max-min optimization of (4) can be solved in two steps. First, solve the minimization problem with respect to the choice of the beliefs, which implies a transformation of the original utility function (4) into a non-expected recursive utility function of the form

$$V_t = (C_t L_t^\eta)^{1-\beta}[E_t(V_{t+1})^{1-\psi}]^{\frac{\beta}{1-\psi}}, \tag{5}$$

where the coefficient ψ is related to κ through the following equation

$$\psi = 1 + \frac{1}{\kappa(1-\beta)}$$

showing that $\psi \geq 1$. In particular, $\psi = 1$ corresponds now to the rational expectations model. In (5), we have restricted the utility flow to the form $U(C_t, L_t) = \ln C_t + \eta \ln L_t$.[8] A further implication of the above minimization problem is that the martingale increment g_{t+1} at optimum can be written in terms of the non-expected recursive utility as

$$g_{t+1} = \frac{V_{t+1}^{1-\psi}}{E_t {V_{t+1}}^{1-\psi}}. \tag{6}$$

As a second step, using (5), find the optimal allocation of consumption and leisure under the standard budget constraint which will be discussed in the next section.

There are alternative interpretations of the above framework which have been given in the literature. In particular, Maccheroni et al. (2006) have shown that the above-defined multiplier preferences are special cases of variational preferences. Hansen and Sargent (2007) have also shown the link between multiplier preferences and the smooth ambiguity formulation of

[8]This risk-adjusted utility function coincides with that of the preferences described in Kreps and Porteus (1978) and Epstein and Zin (1989). In that context, ψ represents the risk-aversion coefficient, while in our framework ψ is a measure of the degree of ambiguity.

Klibanoff et al. (2009).

3 Model

3.1 Households

In this section, we present the model economy, which consists of a standard New-Keynesian closed-economy model with a continuum of firms and households along the lines of King and Wolman (1996) and Yun (1996) where we abstract from monetary frictions. As discussed in the previous section, preferences of the representative household are non-standard and given by (4) where the martingale increment is optimally chosen as in (6) where V_t is given by (5). In (4), C_t is a Dixit-Stiglitz aggregator of the continuum of consumption goods produced in the economy

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

where θ, with $\theta > 0$, is the elasticity of substitution across the consumption goods and $c_t(j)$ is the consumption of the individual good j; L_t is leisure.

Households are subject to a flow budget constraint of the form

$$x_t Q_t + P_t(C_t + I_t) + T_t = x_{t-1} (Q_t + D_t) + W_t N_t + P_t^k K_t, \tag{7}$$

where W_t denotes the nominal wage received in a common labor market; N_t is labor (notice that $N_t + L_t = 1$); P_t^k represents the nominal rental rate of capital, K_t, which is rented in a common market to all firms operating in the economy; x_t is a vector of financial assets held at time t, Q_t the vector of prices while D_t the vector of dividends; P_t is the consumption-based price index given by

$$P_t = \left[\int_0^1 P_t(j)^{1-\theta} dj \right]^{\frac{1}{1-\theta}},$$

where $P_t(j)$ is the price of the individual good j. Finally T_t represents government's lump-sum taxes, and I_t investment. Given K_t and I_t, next-period capital stock is given by

$$K_{t+1} = \left(1 - \delta - \phi\left(\frac{I_t}{K_t}\right)\right) K_t + I_t, \tag{8}$$

where δ, with $0 < \delta < 1$, represents the depreciation rate and $\phi(\cdot)$ is a convex function of the investment-to-capital ratio. The convexity of the adjustment-cost function captures the idea that is less costly to change the capital stock slowly. It implies that the value of installed capital in terms of consumption varies over the business cycle, therefore the model implies a non-trivial dynamic for the Tobin's q.

Households maximize expected utility (4) by choosing the sequences of consumption, capital, leisure and portfolio holdings under the flow budget constraint (7), the law of accumulation of capital (8) and an appropriate transversality condition. Standard optimality conditions imply the equalization of the marginal rate of substitution between consumption and leisure to the real wage

$$\frac{U_l(C_t, L_t)}{U_c(C_t, L_t)} = \frac{W_t}{P_t}. \tag{9}$$

The first-order conditions with respect to asset holdings imply the standard orthogonality condition between the stochastic discount factor and the asset return

$$\tilde{E}_t\{M_{t,t+1} R^j_{t+1}\} = 1, \tag{10}$$

where $M_{t,t+1}$ is the nominal stochastic discount factor between period t and $t+1$ defined by

$$M_{t,t+1} \equiv \beta \frac{U_c(C_{t+1}, L_{t+1})}{U_c(C_t, L_t)} \frac{P_t}{P_{t+1}}, \tag{11}$$

and R^j_{t+1} is the one-period nominal return on a generic asset j given by $R^j_{t+1} \equiv (Q^j_{t+1} + D^j_{t+1})/Q^j_t$. Moreover, by defining with $m_{t,t+1}$ the real stochastic discount factor, as $m_{t,t+1} =$

$M_{t,t+1}P_{t+1}/P_t$, we can write the optimality condition with respect to capital as an orthogonality condition of the form

$$\tilde{E}_t\{m_{t,t+1}r^K_{t+1}\} = 1, \tag{12}$$

where the real return on capital is defined by

$$r^K_{t+1} \equiv \frac{1}{q_t}\frac{P^k_{t+1}}{P_{t+1}} + \left[1 - \delta - \phi\left(\frac{I_{t+1}}{K_{t+1}}\right) + \phi'\left(\frac{I_{t+1}}{K_{t+1}}\right)\frac{I_{t+1}}{K_{t+1}}\right]\frac{q_{t+1}}{q_t}, \tag{13}$$

and in particular q_t denotes the model Tobin's q given by

$$q_t = \frac{1}{1 - \phi'\left(\frac{I_t}{K_t}\right)}. \tag{14}$$

Tobin's q measures the consumption cost of a marginal unit of capital and is increasing with the investment-to-capital ratio. The return on capital, described in (13), is given by two components: the first one captures the return on renting capital to firms in the next period, while the second component captures the benefits of additional units of capital in building up capital stocks for the future rental markets.

3.2 Firms

There is a continuum of firms of measure one producing the respective consumption goods using a constant-return-to-scale technology given by

$$Y_t(j) = (K^j_t)^\alpha(A_tN^j_t)^{1-\alpha}, \tag{15}$$

for each generic firm j where A_t represents a common labor-productivity shifter and α, with $0 < \alpha < 1$, is the capital share. Given the Dixit-Stiglitz aggregator, a generic firm j faces the following demand

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

where total output, Y_t, is equal to consumption and investment

$$Y_t = C_t + I_t. \tag{16}$$

Households own firms which distribute profits in the forms of dividends. Given (10), the value of a generic firm j is given by

$$Q_t^j = \tilde{E}_t\{M_{t,t+1}(D_{t+1}^j + Q_{t+1}^j)\}, \tag{17}$$

where nominal dividends are defined as

$$D_t^j = P_t(j)Y_t(j) - W_t N_t^j - P_t^k K_t^j. \tag{18}$$

Given (17) and (18), the nominal value of a generic firm j *cum* current dividend is given by

$$Q_t^j + D_t^j = \tilde{E}_t\left\{\sum_{T=t}^{\infty} M_{t,T}[P_T(j)Y_T(j) - W_T N_T^j - P_T^k K_T^j\right\},$$

where $M_{t,t} = 1$.

We assume that firms choose prices, capital and labor to maximize the firm's value *cum* current dividend. In particular, cost minimization under the production function (15) implies that total costs are linear in current output

$$W_t N_t^j + P_t^k K_t^j = \left(\frac{W_t}{A_t(1-\alpha)}\right)^{1-\alpha}\left(\frac{P_t^k}{\alpha}\right)^{\alpha} Y_t(j),$$

and that the capital-to-labor ratio is equalized across firms

$$\frac{K_t^j}{N_t^j} = \frac{\alpha}{1-\alpha}\frac{W_t}{P_t^k}. \tag{19}$$

Firms are subject to price rigidities as in the Calvo mechanism. In particular, at each point in time, firms face a constant probability $(1-\gamma)$, with $0 < \gamma < 1$, of adjusting their price which is independent of the last time the price was re-set. Firms, which can adjust their price $P_t(j)$ in period t, set it by maximizing the present-discounted value of the firm *cum* current dividend considering that prices set at time t will last until a future time T with probability γ^{T-t}.

The optimal price decision together with the Calvo price mechanism implies the following AS equation

$$\frac{1-\gamma\Pi_t^{\theta-1}}{1-\gamma} = \left(\frac{F_t}{Z_t}\right)^{\theta-1}, \tag{20}$$

in which the gross inflation rate is given by $\Pi_t = P_t/P_{t-1}$ and Z_t is given by the following expression

$$Z_t \equiv \mu\tilde{E}_t\left\{\sum_{T=t}^{\infty}(\beta\gamma)^{T-t}U_c(C_T,L_T)\left(\frac{W_T}{A_T(1-\alpha)}\right)^{1-\alpha}\left(\frac{P_T^k}{\alpha}\right)^{\alpha}Y_T\right\}, \tag{21}$$

in which we have defined the mark-up as $\mu \equiv \theta/(1-\theta)$. Moreover F_t, in equation (20), is given by

$$F_t \equiv \tilde{E}_t\left\{\sum_{T=t}^{\infty}(\beta\gamma)^{T-t}U_c(C_T,L_T)Y_T\right\}. \tag{22}$$

3.3 Equilibrium

In equilibrium, aggregate output is used for consumption and investment as in (16). Financial market equilibrium requires that households hold all the outstanding equity shares and that all the other assets are in zero net supply.

Capital and labor markets are also in equilibrium

$$K_t = \int_0^1 K_t^j dj$$

$$N_t = \int_0^1 N_t^j dj.$$

In particular, equilibrium in the labor market implies

$$N_t = \int_0^1 N_t^j dj = \frac{1}{A_t^{1-\alpha}} \left(\frac{N_t}{K_t}\right)^{\alpha} Y_t \Delta_t \tag{23}$$

where Δ_t is a measure of price dispersion defined by

$$\Delta_t \equiv \int_0^1 \left(\frac{p_t(i)}{P_t}\right)^{-\theta} di,$$

which follows the law of motion

$$\Delta_t = \gamma \pi_t^{\theta} \Delta_{t-1} + (1-\gamma)\left(\frac{1-\gamma \Pi_t^{\theta-1}}{1-\gamma}\right)^{\frac{\theta}{\theta-1}}. \tag{24}$$

Finally, lump-sum taxes are adjusted to balance revenues and costs for the government in each period.

Given the process for the stochastic disturbances $\{A_t\}$, initial conditions $(\Delta_{t_0-1},\, K_{t_0-1})$ and a monetary policy rule, an equilibrium is an allocation of quantities and prices $\{C_t,\, Y_t,\, K_t,\, N_t,\, I_t,\, F_t,\, Z_t,\, P_t,\, P_t^k,\, W_t,\, q_t,\, \Delta_t,\, g_t,\, V_t\}$ such that equations (5), (6), (8), (9), (12), (14), (16), (19), (20), (21), (22), (23), (24) hold, considering the definitions of the following variables $M_{t,t+1}$, r_t^k, L_t, Π_t, which are given in the text, and considering that the distorted expectation operator is related to the reference expectation operator through (3).

4 Optimal policy problem

In this section, we study optimal policy from a normative perspective. In our environment, the issue of which objective to maximize is subtler than under the benchmark case of no model uncertainty, extensively discussed in the literature. In the standard Ramsey approach this should coincide with the utility of the households. Things are more complicated here because, as discussed in Barillas et al (2009), model uncertainty is just in the head of the agents: they have complete knowledge of the "reference" probability distribution, which is the "true" distribution, but simply they do not trust it. Therefore, the preferences described in (5) represent more a way to handle decisions in an ambiguous world rather than really the utility agents are getting. Indeed, at the end, states of nature will be realized through the "reference" probability distribution.

We present two alternative approaches to welfare analysis: the "benevolent" policymaker and the "paternalistic" policymaker. The "benevolent" policymaker commits to maximize the preferences through which agents make their decisions in the economy. In this case, the objective to maximize is given by (4) or, equivalently, by (5). A "paternalistic" policymaker instead commits to maximize the present discounted value of the utility flows

$$E_{t_0} \sum_{t=t_0}^{\infty} \beta^{t-t_0} U(C_t, L_t), \tag{25}$$

where expectations are taken under the "reference" probability distribution, which governs the realization of the states of nature. The objective (25) is the expected utility that agents will receive ex-ante if they were trusting the model, but also the utility in the long-run when model uncertainty is resolved.[9] It should be clear that under the "paternalistic" policymaker there is no additional information problem, or asymmetry, nor the policymaker

[9] In an optimal taxation problem, Karantounias (2009) analyzes this case as the relevant one, calling it the Ramsey policymaker. Karantounias (2011), in the same environment, considers a policymaker who also expresses doubts on the reference probability distribution.

can reveal more to the agents than what they already know by maximizing a different objective rather than the one agents are using for their choices. Indeed, the "reference" probability distribution is part of the information that agents have: they are told that this is the "true" probability distribution– simply they do not trust it.[10]

We are interested in characterizing optimal policy under commitment. The "benevolent" policymaker, in this case, seeks to maximize (4) or V_{t_0} in (5) by choosing the sequences $\{C_t$, Y_t. K_t, N_t, I_t, F_t, Z_t, P_t, P_t^k, W_t, q_t, Δ_t, g_t, $V_t\}$ under the constraints (5), (6), (8), (9), (12), (14), (16), (19), (20), (21), (22), (23), (24) given the process for the stochastic disturbance $\{A_t\}$ and initial conditions $(\Delta_{t_0-1}, K_{t_0-1})$, given the relationship between leisure and labor, $L_t = 1 - N_t$, considering the definitions of the variables $m_{t,t+1}$, r_t^k, Π_t, and that the distorted expectation operator is related to the "reference" expectation operator through (3). Instead, the "paternalistic" policymaker commits to maximize the objective (25) under the same constraints of the "benevolent" policymaker.

Given that the two optimal policy problems are time-inconsistent because of the presence of forward-looking constraints, we add other constraints on initial values to write the problem in a recursive way, as discussed among others by Benigno and Woodford (2011). Our solution method is to consider the set of non-linear first-order conditions of the two optimal policy problems under this stronger form of commitment. We proceed as follows. First, we compute the optimal policy in the non-stochastic steady state, where there is no model uncertainty. Second, using standard perturbation techniques, we take a first and, when needed, a second-order approximation, around the non-stochastic steady state, to the non-linear stochastic first-order conditions of the optimal policy problem (discussed above), and study the resulting equilibrium allocation.

We calibrate the structural parameters of the model consistently with existing results in

[10] In Klibanoff et al. (2009) the rational expectations objective function under the "true" probability distribution is also an interesting reference point since the utility of the agents will converge to it in the long run when the set of alternative probability distribution is finite.

the macroeconomic literature. In particular, following Christiano, Eichenbaum and Evans (2005), we set $\alpha = 0.36$ which corresponds to a steady-state share of capital income equal to roughly 36 percent. We set $\delta = 0.025$, which implies a rate of capital depreciation equal to 10 percent at annual rates. This value of δ is roughly equal to the estimates reported in Christiano and Eichenbaum (1992). In addition, we set the coefficient of the demand elasticity with respect to prices, θ, equal to 6, implying a steady-state price mark-up of 20 percent.[11] We choose $\eta = 0.45$ to match a steady state Frisch elasticity of labor supply of 1.8, as estimated by Smets and Wouters (2007) on U.S. data. We set $\gamma = 0.6$ to match the frequency of price adjustment estimated by Klenow and Kryvtsov (2008) and Christiano, Eichenbaum and Evans (2005). Following Jermann (1998), we set the second-derivative of the adjustment-cost function $\phi(\cdot)$ evaluated at the steady state in such a way that $1/\bar{\phi}'' = 0.25$, which corresponds to the steady-state elasticity of the investment-to-capital ratio with respect to Tobin's q. We assume the following random-walk process for productivity

$$\log(A_{t+1}) = \zeta + \log(A_t) + \varepsilon_{t+1},$$

where ε_{t+1} has zero mean and standard deviation σ, and ζ is a drift in technology. We assume $\sigma = 0.012$ and $\zeta = 0.003$ to match respectively the volatility and the mean of U.S. quarterly total factor productivity estimated by Fernald (2008). The model is consistent with a balanced-growth path, and therefore we can obtain a stationary representation by re-scaling the appropriate variables through the level of productivity. We study optimal policy for different values of the parameter $\psi \in \{1, 25, 50, 100\}$. In particular, $\psi = 1$ represents the benchmark model of rational expectations, while $\psi = 100$ is the degree of model uncertainty at which our model matches the average U.S. equity premium of 5.5% per year, as estimated by Fama and French (2002).[12] Finally, the discount factor is set equal to $\beta = 0.99$, implying

[11] Similar values are obtained in Smets and Wouters (2007).

[12] The 5.5% equity premium is obtained under a Taylor rule, which requires the risk-free nominal interest rate, R^f, in log-deviations from its steady state, $\bar{R}^f$, to evolve according to $\ln R_t^f/\bar{R}^f = \rho_r \ln R_{t-1}^f/\bar{R}^f +$

an average real interest rate of one percent at $\psi = 100$.

4.1 Results

Figures 1 and 2 show the impulse responses of selected variables to a one standard deviation shock to technology under different values of the parameter ψ for the "benevolent" policymaker, while Figures 3 and 4 show the results to the same experiment for the "paternalistic" policymaker.

FIGURE 1 HERE

FIGURE 2 HERE

The case $\psi = 1$ corresponds to the benchmark model of rational expectations. As it is well known, price stability, and therefore replicating the flexible-price allocation, is the optimal policy.[13] Following a permanent productivity shock, consumption and output steadily increase towards their new higher steady-state levels. The real and nominal interest rates rise on impact and steadily decline to sustain the increase over time in consumption. The return on capital, the Tobin's q and therefore investment increase on impact.

FIGURE 3 HERE

FIGURE 4 HERE

When agents face ambiguity, the optimal policies run by a "benevolent" or a "paternalistic" policymaker are quite different. The striking result is that the equilibrium outcome implied by the "benevolent" policymaker is similar to that of the benchmark model, without ambiguity, and this is true for any degree of model uncertainty. As shown in Figures 1 and

$(1 - \rho_r)\left[\phi_\pi E_t \ln \Pi_{t+1}/\bar{\Pi} + \phi_x \ln Y_t/Y_t^*\right]$, where $\ln \Pi_t/\bar{\Pi}$ is the log-deviation of the inflation rate from its steady state $\bar{\Pi}$ and $\ln Y_t/Y_t^*$ is the output gap (in logs), where Y_t^* is the potential output that would arise under flexibile prices and frictionless physical capital accumulation. Parameters of the policy rule are set to values estimated by Clarida et al. (2000): $\rho_r = 0.93$, $\phi_\pi = 2.15$ and $\phi_x = 0.79$.

[13] See Khan, King and Wolman (2003) and Woodford (2009b) for a discussion of optimal policy in this case.

2, there are marginal deviations from a policy of price stability.[14] Instead, the policy chosen by the "paternalistic" policymaker changes quite substantially and the more the higher the degree of model uncertainty. As shown in Figures 3 and 4, the optimal policy of the "paternalistic" policymaker becomes very accommodative. Inflation increases on impact and then steadily declines toward zero. This increase is higher, the higher is the degree of model uncertainty. Nominal interest rates become more volatile: first, they decrease and afterward they rise. In the short run, the real rate now falls; consumption and output increase on impact even to overshoot their long-run levels. The Tobin's q jumps at higher levels leading to a larger change in investment. As ψ increases, optimal policy under the "paternalistic" policymaker becomes more and more accommodative to the technology shock. Moreover, the higher ψ is, the higher is the volatility of the return on equity and capital and the price of equity and capital. For instance, after a one standard deviation increase in total factor productivity, equity return and Tobin's q increase on impact by 0.72% and 0.17 %, respectively, if $\psi = 1$, while they jump to 1.05% and 0.52% if $\psi = 100$. At optimal policy, welfare evaluated through the objective of the "paternalistic" policymaker in (25) increases by about 5% with respect to a policy of price level stabilization if $\psi = 100$.

To sum up, when policy is run by a "benevolent" policymaker there are no significant deviations from a price-stability policy. Instead a "paternalistic" policymaker would choose a more pro-cyclical response of inflation which "over - accommodates" the technology shock. Such an increase in inflation is accompanied by an increase in the volatility of quantity variables, such as output, investment and consumption, as well as in the volatility of asset prices, such as the Tobin's q, the equity and capital returns, the nominal and real interest rates. The larger the degree of distortion in beliefs, the larger the departure of optimal policy from price stability.

[14] Our results are different from the model of Levin et al. (2008), which uses Epstein-Zin preferences, since they also include utility from money balances.

5 Why does model uncertainty matter for optimal policy?

The objective of this section is to explain why model uncertainty matters for optimal policy when the policymaker is "paternalistic" and why it does not matter when the policymaker is "benevolent". To this end, we need to study how model uncertainty and ambiguity interact with the other distortions present in the economy, and how the transmission of monetary policy is affected by each of them. Our model features four types of distortions that affect equilibrium allocations: sticky and staggered prices, monopolistic competition, capital adjustment costs, and distorted beliefs which indeed originate from doubts and ambiguity. We briefly discuss the nature of each of the four distortions while we also show, borrowing from the analysis of Khan, King and Wolman (2003), how we can selectively eliminate each of them in turn through the use of state contingent taxes or subsidies or through other instruments.

The markup distortion. Monopolistic competition in the goods market produces an inefficient wedge between the marginal rate of transformation and the marginal rate of substitution between consumption and labor. Markup distortions act as a tax on firms' revenues. Therefore, to remove the aggregate implications of steady-state markup, we can use a subsidy to firms' sales such that $\tau^s = \mu - 1$.

Relative-price distortion. When the price level varies over time, a staggered price-adjustment mechanism generates price dispersion across firms setting prices at different times and therefore an inefficient allocation of resources among goods that are produced according to the same technology. This can be seen by inspecting equations (23) - (24), where the natural measure of this distortion is given by Δ_t: everything else being equal, higher inflation requires more labor to produce the same amount of output. Given the way relative-price distortions affect the equilibrium allocations, they can be thought of an additive productivity shock relative to the case of no distortion. To eliminate this distortion, we can set in each period a level of government spending, Υ_t, such that $\Upsilon_t = \left(1/\Delta_t - 1/\bar{\Delta}\right) K_t^{\alpha} \left(A_t N_t\right)^{1-\alpha}$, where $\bar{\Delta}$ is the level of price dispersion in the non-stochastic steady state.[15]

The distortion in the accumulation of physical capital. Adjustment costs in physical capital introduce an inefficient wedge between the price of investment and the price of installed capital, captured by the Tobin's q in equation (14). If Tobin's q deviates from unity, i.e. $q_t \neq 1$, the equilibrium investment, and therefore output, is inefficient, and q_t measures such inefficiencies. In order to remove this distortion, we can think of a fiscal authority subsidizing investments in physical capital with a subsidy given by $\tau_t = \phi\left(\frac{I_t}{K_t}\right) K_t$.

Beliefs' distortions. Distortions in beliefs affect equilibrium allocations through forward-looking decisions. In our model, agents make two types of forward-looking decisions: on the one side the choice on how much capital to accumulate, and on the other side the price-setting decision. Concerning the first choice, everything else being equal, distorted beliefs cause an inefficient accumulation of capital. In a second-order approximation, the excess return on capital with respect to the risk-free rate, adjusted by the Jensen's inequality, can be written as

$$E_t \hat{r}_{t+1}^K - r_t^f + \frac{1}{2} Var_t \hat{r}_{t+1}^K = -cov_t(\hat{m}_{t,t+1}, \hat{r}_{t+1}^K) - cov_t(\hat{g}_{t+1}, \hat{r}_{t+1}^K),$$

where variables with hats denote deviations from the steady state. The distortions in the beliefs add an additional term to the premium on the capital return, which now depends on the covariance between the return on capital and the distortions in the beliefs $\hat{g}_{t+1}$. This additional term leads to an inefficient accumulation of capital, under a policy of price stability. Indeed, in this case, the return on capital is positively correlated with the current and long-run level of technology and therefore negatively correlated with $\hat{g}_{t+1}$. To see why

[15] We assume that government spending is zero in the non-stochastic steady state. This choice should make more transparent the role of this distortion, due to price dispersion, as opposed to that due to monopolistic competition for the analysis of optimal monetary policy.

$\hat{g}_{t+1}$ depends negatively on the long-run level of technology, take a first-order approximation of equations (5) and (6) and assume that β is close to unitary value, then $\hat{g}_{t+1}$ can be approximated by

$$\hat{g}_{t+1} \simeq -(\psi - 1)[(E_{t+1}\hat{C}_\infty - E_t\hat{C}_\infty) + \eta(E_{t+1}\hat{L}_\infty - E_t\hat{L}_\infty)].$$

Since the long-run level of leisure does not vary following a permanent productivity shock, a high level of g_{t+1} mainly reflects bad news with respect to long-run consumption which can change because of the stochastic trend in productivity.[16]

The second dimension along which distorted beliefs affect the equilibrium allocation depends on the pricing decisions of firms. To get the intuition on how this channel works, let us consider the aggregate-supply equation under the assumption that capital is fixed meaning that the cost of adjusting capital is infinite and steady-state investment is equal to zero, i.e. $Y_t = C_t$. Under this assumption and with log utility, F_t in equation (22) is constant and given by $F_t = 1/(1 - \beta\gamma)$, whereas Z_t in equation (21) collapses to

$$Z_t \equiv \mu E_t \left\{ \sum_{T=t}^{\infty} (\beta\gamma)^{T-t} S_T \right\} + \frac{\mu}{G_t} \left\{ \sum_{T=t+1}^{\infty} (\beta\gamma)^{T-t} cov_t(S_T, G_T) \right\}. \tag{26}$$

Equation (26), together with (20), makes clear that there exists a positive relationship between inflation and the present discounted value of expected real marginal costs, evaluated under the reference probability measure. The distortion in beliefs affects this relationship through the second term on the right-hand side of (26). If the covariance between the martingale G_t and marginal costs is negative (positive), for given inflation, the present discounted value of expected real marginal costs, i.e. the first term on the right hand side of (26), is higher (lower) than it would be without distortions in beliefs. This implies that for

[16]The fact that the distortion in the beliefs depends mainly on the long-run level of technology also implies that monetary policy has not much power to affect it. However, this does not imply that monetary policy cannot affect the distortions coming from ambiguity, since can still affect returns and therefore covariances.

given inflation and, therefore, for given price dispersion, average markup is lower (higher) than it would otherwise be in absence of distortion in beliefs, if the covariance between the martingale G_t and marginal costs is negative (positive).

To remove each of the two distortions originating from distorted beliefs in a separate way, we can use fiscal instruments that correct for the distorted valuation of the return on capital, in one case, and of future profits in the other case. In particular, the distortion in the physical capital accumulation resembles the distortion caused by a tax proportional to future total asset returns, i.e. including both capital gains and dividends. Therefore, a fiscal authority could remove this distortion by committing to a state-contingent tax or subsidy, τ_{t+1}^K, on the return on capital, r_{t+1}^K, such that $(1-\tau_{t+1}^K)g_{t+1} = 1$. The same tax/subsidy can be used in equation (17) to correct for distorted beliefs in the value of the firm which affects price setting decisions.

5.1 Results

In Figure 5, we present the impulse responses of output, inflation and the real interest rate following a technology shock under the two optimal policy problems of the "benevolent" policymaker (on the right column) and of the "paternalistic" policymaker (on the left column) for the various cases in which we remove each distortion in turn. In the figure the parameter ψ is fixed to $\psi = 100$.

FIGURE 5 HERE

Starting with the "paternalistic" policymaker, we can see that once we remove either the monopolistic-competition distortion or the beliefs' distortions we obtain that the optimal policy is to stabilize inflation to zero as in the case of no model uncertainty. The interaction between these two distortions explains why the "paternalistic" policymaker chooses a more procyclical response of output and inflation following a productivity shock. Given the monopolistic-competition distortion, output and the average real marginal costs are too low.

The policymaker can increase the average real marginal costs, reduce the average mark-up by raising average inflation. In a benchmark model with no ambiguity, this is too costly, as shown in the literature, and price stability dominates as optimal policy. In general, in New Keynesian models, the trade-off between inflation and output is too steep to correct for the distortions due to monopolistic competition. Instead, under model uncertainty, the decision maker can raise real marginal costs without increasing much average inflation provided real marginal costs covary negatively with G_t, and therefore with g_t, as shown in (26). The co-movement between asset prices and marginal cost reduces the severity of the inflation-output trade-off. In fact, by making the stochastic discount factor negatively related with the future real marginal costs, the present discounted value of the firms' real marginal costs does not rise much. Therefore firms do not have much incentive to increase their prices on average.

When we focus on the optimal policy under the "benevolent" policymaker, we notice that the impulse responses change substantially from the full-distortion case only when we remove the distorted beliefs, while keeping (5) as the objective to be maximized. Indeed, the result that the "benevolent" policymaker aims at a policy of price stability, as in the benchmark model without ambiguity hinges on the fact that the distortions in the beliefs of the policymaker and that of the private sector are perfectly aligned. To understand this, consider that the objective function (5) of the "benevolent" policymaker can be written back as (4), where G_t follows the martingale process in which the martingale increment, g_t, is optimally chosen and given by (5)-(6). Under these constraints, the objective function (4) is indeed equivalent to (5). However, since the martingale increment is mainly dependent on the revisions in long-run productivity, the policymaker does not have much room to influence it and the second component of the above expression is quasi independent of policy. This means that the objective of the "benevolent" policymaker can be approximated by

$$E_{t_0} \sum_{t=t_0}^{\infty} \beta^{t-t_0} G_t U(C_t, L_t) = \tilde{E}_{t_0} \sum_{t=t_0}^{\infty} \beta^{t-t_0} U(C_t, L_t). \tag{27}$$

Using this observation, we can further show that we can write all the optimal policy problem (objective and constraints) in terms of the distorted expectation operator. It follows that this problem will be exactly equivalent to that of the benchmark model, without ambiguity, except that the rational-expectation operator is replaced by the distorted-expectation operator. This means that distortions in beliefs would matter for optimal policy, but only through second-order effects whereas, instead, a first-order approximation would show no role for distorted beliefs and deliver a price-stability result similar to the benchmark model without ambiguity. Indeed Figure 5 shows that when we remove the distortions coming from beliefs in both the AS equation and the Euler equation, we find that the "benevolent" policymaker would like to produce a countercyclical response of output and inflation following the productivity shock. With this misalignment in beliefs, the policymaker can exploit the distortion in the beliefs still present in the objective function to improve welfare. Indeed, note that we can write (27) as

$$E_{t_0} \sum_{t=t_0}^{\infty} \beta^{t-t_0} U(C_t, L_t) + \sum_{t=t_0}^{\infty} \beta^{t-t_0} cov_{t_0}[U(C_t, L_t), G_t],$$

where a positive covariance between the martingale G_t and the utility flow is welfare improving. But, since the martingale increment depends negatively on the long-run shock to technology, consumption and output should fall following a positive productivity shock to produce such a positive covariance, as shown in Figure 5.

Table 1 reports the unconditional means of several variables of interest, computed through a second-order approximation, around the non-stochastic steady state, of the first-order conditions of the optimal policy problem. Several cases are presented for both the "paternalistic" and "benevolent" policymakers. The first two columns present the results of the optimal policy problems when all the distortions are included while the other columns remove each distortion in turn. With all the distortions in place, the "paternalistic" policymaker can increase consumption and investment by reducing substantially the average markup as we have already discussed. This comes through movements in asset prices which imply larger premia on the return on capital and equity which are indeed consistent with the data.[17] The interaction between the following two distortions is important for this quantitative result: the presence of doubts and the adjustment costs on capital. Without the latter, the capital and equity premia are of smaller magnitude, while without doubts they are completely negligible, as it is the case under the standard New-Keynesian model. This shows that our framework represents an improvement upon the modelling present in the literature along the direction of matching also financial data.[18] This is not really a novelty for partial equilibrium analysis that have explained the equity premium through doubts, as Barillas et al . (2009). However, an important insight from a general equilibrium analysis is that policy matters a lot for the size of the risky-asset premia which are higher for the "paternalistic" policymaker.

TABLE 1 HERE

Furthermore, notice that, without the mark-up distortions, the optimal policy under the two cases coincide since the incentive to correct the monopolistic distortion disappears completely for the "paternalistic" policymaker. Finally, when we remove doubts from the private-sector reaction function, the "benevolent" policymaker can improve upon average investment through his/her countercyclical policy.

6 Greenspan, a "paternalistic" policymaker in our model?

In the last section, we have shown that a "paternalistic" policymaker brings the economy to depart in a significant way from the optimal policy of price stability found in a standard New-Keynesian model. Instead, a more procyclical response of output and consumption is desirable with movements in asset prices which are consistent with significant values for

[17] The equity return refers to the return implied by movements in the values of the firms, at the aggregate level, and their dividends.

[18] The premia on risky assets rise with the increase in the degree of ambiguity, ψ.

the premia on risky assets. In this section we evaluate Alan Greenspan's policy from the perspective of the policy implied by a "paternalistic" policymaker. We model Greenspan's policy through an interest rate rule for the risk-free nominal interest rate R_t^f

$$\ln\left(\frac{R_t^f}{\bar{R}^f}\right) = \rho_r \ln\left(\frac{R_{t-1}^f}{\bar{R}^f}\right) + (1-\rho_r)\left(\phi_\pi \ln\frac{\Pi_t}{\bar{\Pi}} + \phi_y \ln\frac{Y_t}{Y_t^*}\right), \tag{28}$$

where $\bar{R}$ and $\bar{\Pi}$ are steady-state values for the respective variables and Y_t^* is potential output, defined as the equilibrium level of output with flexible prices and no capital-adjustment costs. We estimate (28) on the sample period corresponding to Greenspan as chairman of the Federal Reserve, 1987:3-2006:1.[19] We obtain $\rho_r = 0.9$, $\phi_\pi = 0.99$ and $\phi_y = 0.75$. We then solve our model under the estimated policy rule (28) at a degree of model uncertainty $\psi = 100$.

FIGURE 6 HERE

In Figure 6 we plot impulse responses of selected variables under Greenspan's policy against the responses obtained under the optimal policy of both the "benevolent" and "paternalistic" policymakers in our model. As benchmark of comparison, we also plot the impulse responses under the classic Taylor Rule, i.e. the interest rate rule (28) evaluated at $\rho_r = 0$, $\phi_\pi = 1.5$ and $\phi_y = 0.5$. In addition, notice that optimal policy under the "benevolent" policymaker is very close to a policy of inflation targeting in our model. As Figure 6 illustrates, under Greenspan's policy, impulse responses of output, consumption, investment, Tobin's q, real risk-free rate and inflation to a productivity shock are relatively close to the optimal policy of the "paternalistic" policymaker, substantially closer than the "benevolent" policymaker or the Taylor Rule. However, our exercise also suggests that Greenspan was perhaps too accommodative with respect to productivity shocks. For instance, output under

[19] The rule (28) has been estimated with the method of instrumental variables suggested by Clarida et al. (2000). Instruments are the four lags of inflation, output gap, M2 growth rate (FM2), commodity price inflation (PSCCOM) and the spread between the long-term bond rate (FYGL) and the three-month Treasury Bill rate (FYGM3).

Greenspan's policy rises on impact by about 25% more than it should when compared to the optimal policy of the "paternalistic" policymaker. In contrast, output under "benevolent" policymaker or the Taylor Rule increases on impact by only about 1/3 of what it should at optimal policy for the "paternalistic" policymaker in our model.

Remember from previous discussion that strict inflation targeting would roughly approximate optimal policy response to a productivity shock in absence of any model uncertainty, i.e. $\psi = 1$. Therefore, while Greenspan's policy would seem too expansionary from the perspective of a standard New-Keynesian model, it appears to be much closer to optimal policy of a "paternalistic" policymaker when evaluated from the perspective of our New-Keynesian model with model uncertainty.[20]

7 Conclusion

In this paper, we departed from the standard New-Keynesian monetary model by introducing doubts. In our model, households express distrust regarding the true probability distribution. These doubts are reflected in asset prices and might generate, together with ambiguity aversion, equity premia of similar size as those found in the data. This is an important feature of our framework with respect to the benchmark model which, on the contrary, is unable to match asset-price data. In this environment we study optimal policy from the perspective of two policymakers: a "benevolent" policymaker who cares about the utility through which agents act and a "paternalistic" policymaker who instead cares about the utility agents would have if they were not dubbing the model.

Results change in a substantial way with respect to the benchmark model when the policymaker is "paternalistic". A standard finding of the literature is the optimality of a policy of price stability following productivity shocks. In our model with doubts, we

[20] In Benigno and Paciello (2010) we discuss the implementation with simple inflation-targeting rules which also include the response to asset prices.

find that a “paternalistic” policymaker should become more accommodative with respect to productivity shocks and work to increase the equity premium. The departure is larger, the higher is the degree of distrust that agents have. Instead, a “benevolent” policymaker would get close to the optimal policy of the benchmark model since in this case distorted beliefs have only second-order effects. Indeed, the distorted beliefs in the objective function of the policymaker are aligned with those in the forward-looking private-sector reaction functions.

There are several limitations of our modeling strategy. First, we assume that households and firms share the same degree of doubts. Households’ doubts are reflected in Arrow-Debreu prices and those are used to evaluate both asset prices and the future profits of the firms. Results can change if within the private sector there are different degrees of doubts on the model. Second, we assume that the only disturbance affecting the economy is a productivity shock. Results would not change if we were allowing for mark-up shocks modeled using a stationary process. Indeed, doubts and ambiguity aversion are reflected in fears of bad news regarding long-run consumption. Transitory mark-up shocks, contrary to persistent productivity shocks, do not have much influence on long-run consumption. Third, an interesting case to analyze is one in which the policymaker distrusts the reference probability distribution with a different degree of ambiguity than the private sector. However, along these lines, the optimal policy of our “paternalistic” policymaker would be interpreted as that of a policymaker who completely trusts the model while the optimal policy of the “benevolent” policymaker would be interpreted as that of a policymaker who has the same degree of distrust as the private sector. We leave the analysis of the intermediate cases for future work.[21] Finally, we have abstracted from credit frictions and asset-market segmentation which can be important features to add to properly model asset prices and the transmission mechanism of shocks. This is also material for future works. Here, we have kept the analysis the closest as possible to the benchmark New-Keynesian model to show how a small departure from that

[21] See Karantounias (2011) for an extensive analysis applied to the optimal taxation literature.

model delivers important differences in the policy conclusions and how this departure can rationalize a too accommodative monetary policy as an optimal policy following productivity shocks.

References

[1] Barillas, Francisco, Hansen, Lars and Thomas Sargent (2009), "Doubts or Variability?" *Journal of Economic Theory*, Volume 144, Pages 2388-2418.

[2] Benigno, Pierpaolo and Luigi Paciello (2010), "Monetary Policy, Doubts and Asset Prices," NBER working paper No. 16386.

[3] Benigno, Pierpaolo and Michael Woodford (2011), "Linear-Quadratic Approximations of Optimal Policy Problem," forthcoming in the *Journal of Economic Theory.*

[4] Christiano, Lawrence J. and Martin Eichenbaum (1992), "Current Real-Business-Cycle Theories and Aggregate Labor-Market Fluctuations", *American Economic Review*, 82 (3), June, pages 430-50.

[5] Christiano, Lawrence J., Eichenbaum, Martin and Charles L. Evans, (2005), "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy*, University of Chicago Press, vol. 113(1), pages 1-45.

[6] Clarida, R., Gali J. and Mark Gertler,. (2000), "Monetary Policy Rule and Macroeconomic Stability," *Quarterly Journal of Economics*, Vol. 115, No. 1, pages 147-180.

[7] Dennis, Richard, Kai Leitemo and Ulf Soderstrom (2009), "Monetary Policy in a Small Open Economy with a Preference for Robustness," unpublished manuscript, Federal Reserve Bank of San Francisco.

[8] Dupor, Bill (2005), "Stabilizing Non-Fundamental Asset Price Movements under Discretion and Limited Information," *Journal of Monetary Economics*, Volume 52, Issue 4, pages 727-747.

[9] Ellison, Martin and Thomas J. Sargent, "A Defence of the FOMC," CEPR Working Paper No. 7510.

[10] Epstein, Larry and Stanley Zin (1989), "Substitution, Risk Aversion and the Temporal Behavior of Consumption and Asset Returns: A Theoretical Framework," *Econometrica* 57, pp. 937–969.

[11] Fama, Eugene F. and Kenneth R. French (2002), "The Equity Premium," *Journal of Finance*, Vol. 57 No. 2, pp. 637-659.

[12] Fernald, John (2008), "A Quarterly, Utilization-Corrected Series on Total Factor Productivity". mimeo.

[13] Giannoni, Marc (2002), "Does Model Unvertainty Justify Caution? Robust Optimal Monetary Policy In A Forward-Looking Model," *Macroeconomic Dynamics* 6: 114-144.

[14] Greenspan, Alan (2010), "The Crisis," *Brookings Papers on Economic Activity*, forthcoming.

[15] Hansen, Lars and Thomas Sargent (2001), "Robust Control and Model Uncertainty," *American Economic Review* 91: 60-66.

[16] Hansen, Lars and Thomas Sargent (2005), "Robust Estimation and Control under Commitment," *Journal of Economic Theory* 124, pp. 258–301.

[17] Hansen, Lars and Thomas Sargent (2007), "Recursive Robust Estimation and Control without Commitment," *Journal of Economic Theory* 136, pp. 1–27.

[18] Hansen, Lars and Thomas Sargent (2008), *Robustness*, Princeton University Press.

[19] Karantounias, Anastasios (2011), "Managing Expectations, Doubts of the Planner and Fiscal Policy," mimeo, Federal Reserve Bank of Atlanta.

[20] Karantounias, Anastasios (with Lars Hansen and Thomas Sargent) (2009), "Managing Expectations and Fiscal Policy," unpublished manuscript, Federal Reserve Bank of Atlanta.

[21] Khan, Aubhik, Robert G. King and Alexander L. Wolman (2003), "Optimal Monetary Policy," *Review of Economic Studies* 70(4): 825-860.

[22] Klibanoff, P. Massimo Marinacci and S. Mukerji (2009), "Recursive Smooth Ambiguity Preferences," *Journal of Economic Theory* 144: 930-976.

[23] King, Robert G. and Alexander L. Wolman (1996), "Inflation Targeting in a St. Louis Model of the 21st Century," Federal Reserve Bank of St. Louis Review, Vol. 78, no. 3: 83-107.

[24] Kreps, D. M. and E. L. Porteus (1978), "Temporal Resolution of Uncertainty and Dynamic Choice," *Econometrica* 46, pp. 185–200.

[25] Kryvtsov, Oleksiy and Pete Klenow, (2008), "State-Dependent or Time-Dependent Pricing: Does It Matter for Recent U.S. Inflation?", *Quarterly Journal of Economics,* Volume 123, pp. 863-904.

[26] Leitemo, Kai and Ulf Soderstrom (2008), "Robust Monetary Policy in the New Keynesian Framework," *Macroeconomic Dynamics* 12: 126-135.

[27] Levin, Andrew, David Lopez-Salido, Edward Nelson and Tack Yun (2008), "Macroeconometric Equivalence, Microeconomic Dissonance, and The Design of Monetary Policy," *Journal of Monetary Economics* 55: 48-62.

[28] Maccheroni, Fabio, Massimo Marinacci, and Aldo Rustichini (2006) "Ambiguity Aversion, Robustness, and the Variational Representation of Preferences," *Econometrica* 74(6): 1447-1498.

[29] Rudebusch, Glenn D. (2001), "Is the Fed Too Timid? Monetary Policy in an Uncertain World," *Review of Economics and Statistics*, Vol. 83, No. 2, Pages 203-217.

[30] Smets, Frank and Ralf Wouters, (2007), "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach". *American Economic Review*, vol. 97(3), pages 586-606, June.

[31] Tallarini, Thomas D. (2000), "Risk-Sensitive Real Business Cycle," *Journal of Monetary Economics* 45, pp. 507–532.

[32] Taylor, John B. (1993), "Discretion versus Policy Rules in Practice," *Carnegie-Rochester Conference Series on Public Policy,* Volume 39, Pages 195-214.

[33] Taylor John B (2007), "Monetary Policy and House Prices", NBER WP 13682.

[34] Tetlow, Robert J. (2007), "On the Robustness of Simple and Optimal Monetary Policy Rules," *Journal of Monetary Economics* 54: 1397-1405.

[35] Tack Yun (1996), "Nominal Price Rigidity, Money Supply Endogeneity, and Business Cycles," *Journal of Monetary Economics* 37: 345-370.

[36] Woodford, Michael (2009a), "Robustly Optimal Monetary Policy with Near-Rational Expectations," *American Economic Review,* forthcoming.

[37] Woodford, Michael (2009b), "Optimal Monetary Stabilization Policy," unpublished manuscript, Columbia University.

	All Distort.		No Disper.		No Markup		No Tobin q		No Doubts	
	Ben.	Pat.	Ben.	Pat.	Ben.	Pat.	Ben.	Pat.	Ben.	Pat.
Consumption	1.65	1.68	1.65	1.68	1.87	1.87	1.67	1.70	1.58	1.58
Investment	0.51	0.52	0.51	0.52	0.73	0.73	0.53	0.55	0.43	0.42
Hours	0.61	0.62	0.61	0.62	0.66	0.66	0.61	0.62	0.60	0.60
Markup	1.20	1.15	1.20	1.15	1.00	1.00	1.20	1.15	1.20	1.20
Dispersion	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Inflation*	0.00	0.00	0.92	1.60	0.00	0.00	0.00	0.00	-4.80	0.00
Capital Prem.*	0.84	2.90	0.84	2.90	0.76	0.76	0.14	0.87	0.00	0.01
Equity Prem.*	2.95	4.40	2.99	4.40	2.85	2.85	2.66	2.72	0.00	0.02

Table 1: Removing distortions. Means of selected variables at $\psi = 100$; *= in % and at annual rates; Ben. means "benevolent" policymaker; Pat. means "paternalistic" policymaker. All Distort. means the model with all the distortions. No Disper. means eliminating the relative-price distortion. No Markup means eliminating the steady-state mark-up distortion. No Tobin q means eliminating the adjustment cost in capital. No Doubts means eliminating the distortions in the beliefs for the private sector. Markup denotes the gross markup on marginal cost. Dispersion is given by Δ_t. Capital Prem. is the premium on physical capital investments. Equity Prem. is the premium on equity investments.

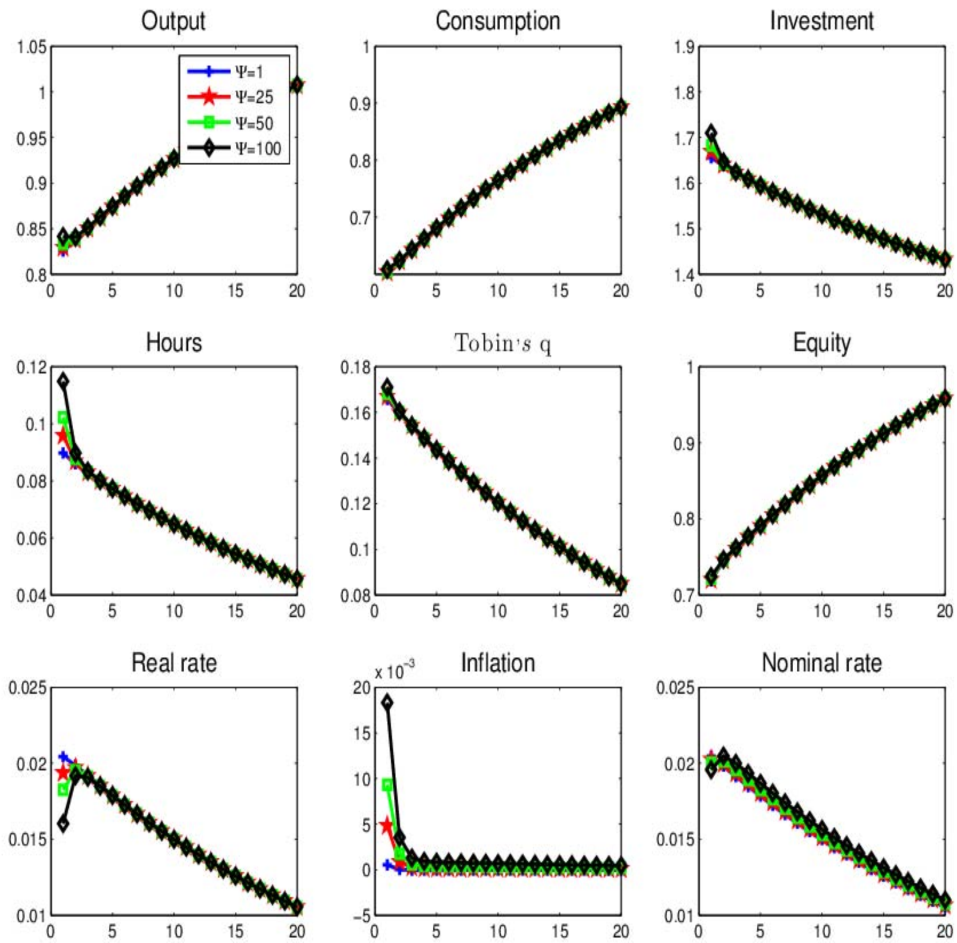

Figure 1: “Benevolent” policymaker, impulse response of selected variables for different values of the degree of ambiguity aversion ψ to a one standard deviation permanent positive productivity shock.

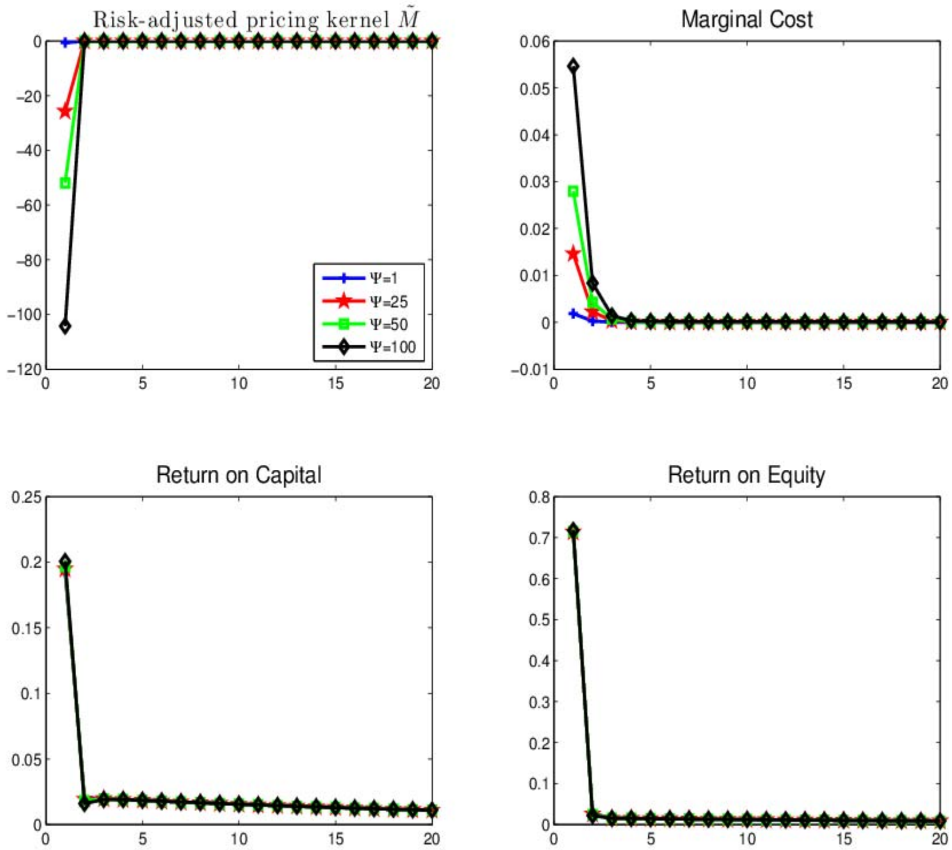

Figure 2: "Benevolent" policymaker, impulse response of selected variables for different values of the degree of ambiguity aversion ψ to a one standard deviation permanent positive productivity shock.

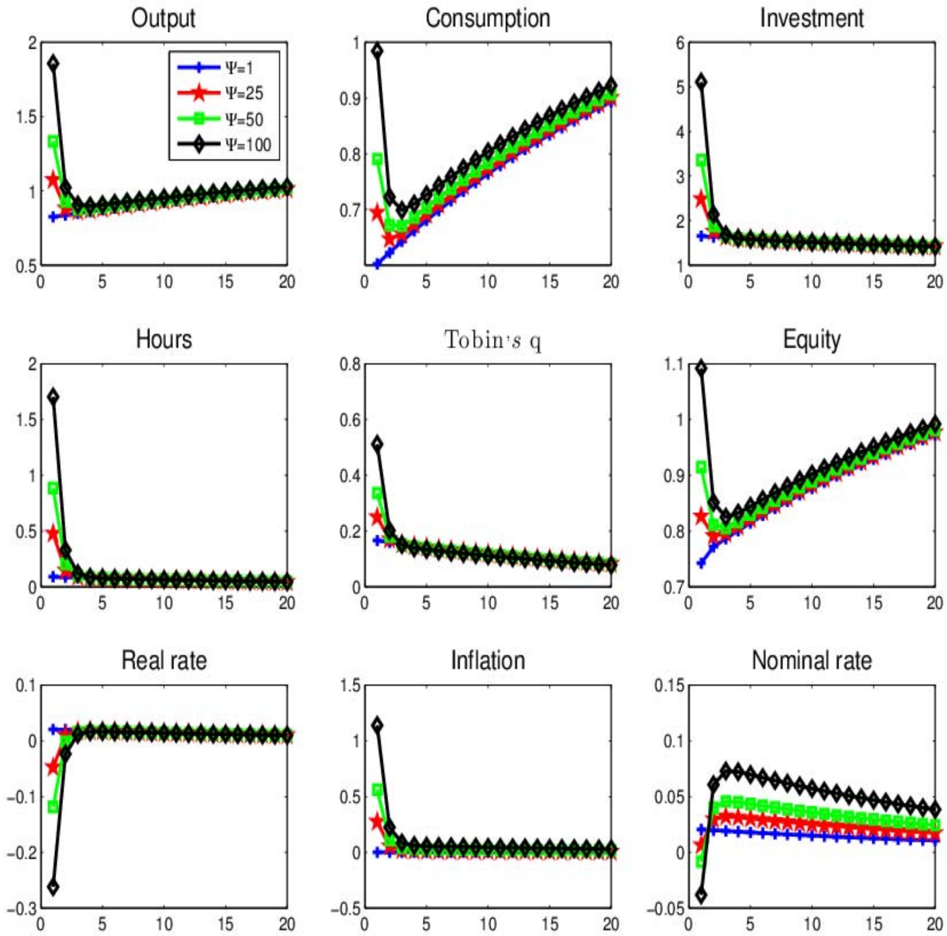

Figure 3: “Paternalistic” policymaker, impulse response of selected variables for different values of the degree of ambiguity aversion ψ to a one standard deviation permanent positive productivity shock.

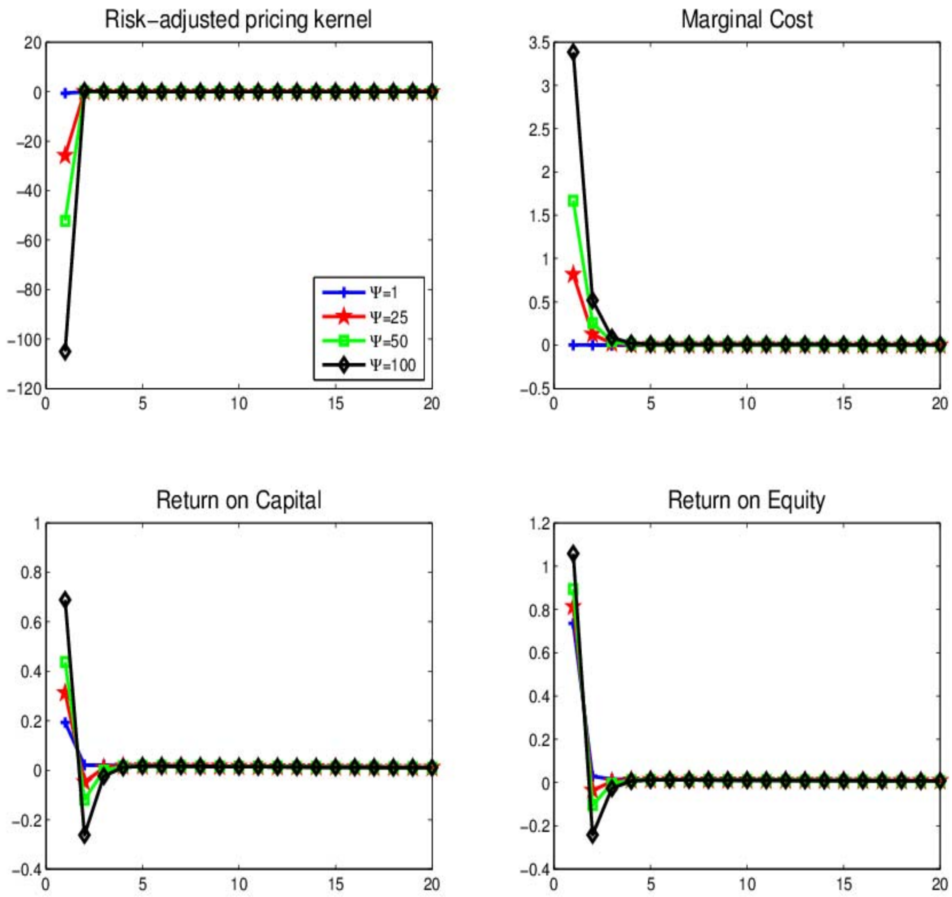

Figure 4: "Paternalistic" policymaker, impulse response of selected variables for different values of the degree of ambiguity aversion ψ to a one standard deviation permanent positive productivity shock.

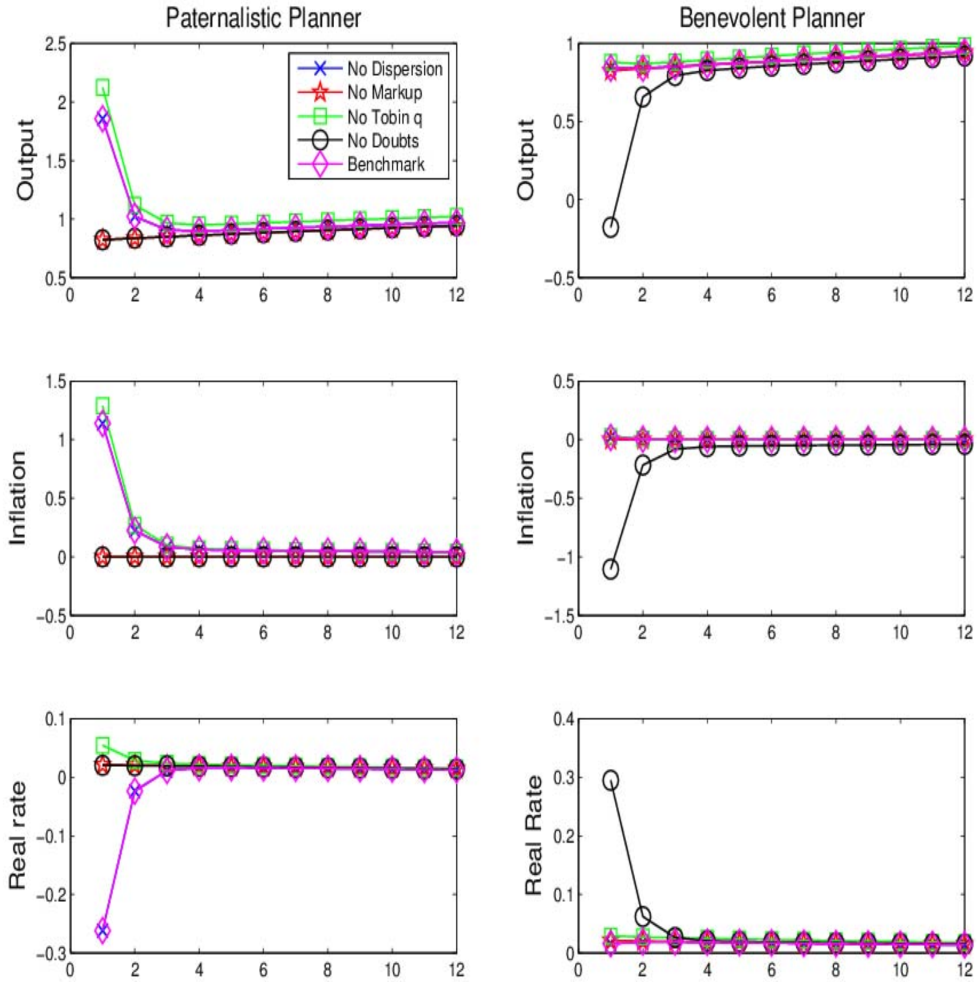

Figure 5: Impulse response of output, inflation and the real rate following a unitary permanent positive productivity shock under optimal policy for a "paternalistic" policymaker on the left column and for a "benevolent" policymaker on the right column where each distortion is eliminated in turn. No Dispersion means eliminating the relative-price distortion. No Markup means eliminating the steady-state mark-up distortion. No Belief means eliminating the distortions in the beliefs for the private sector. No Tobin q means eliminating the adjustment cost in capital. Benchmark means the model with all distortions in place.

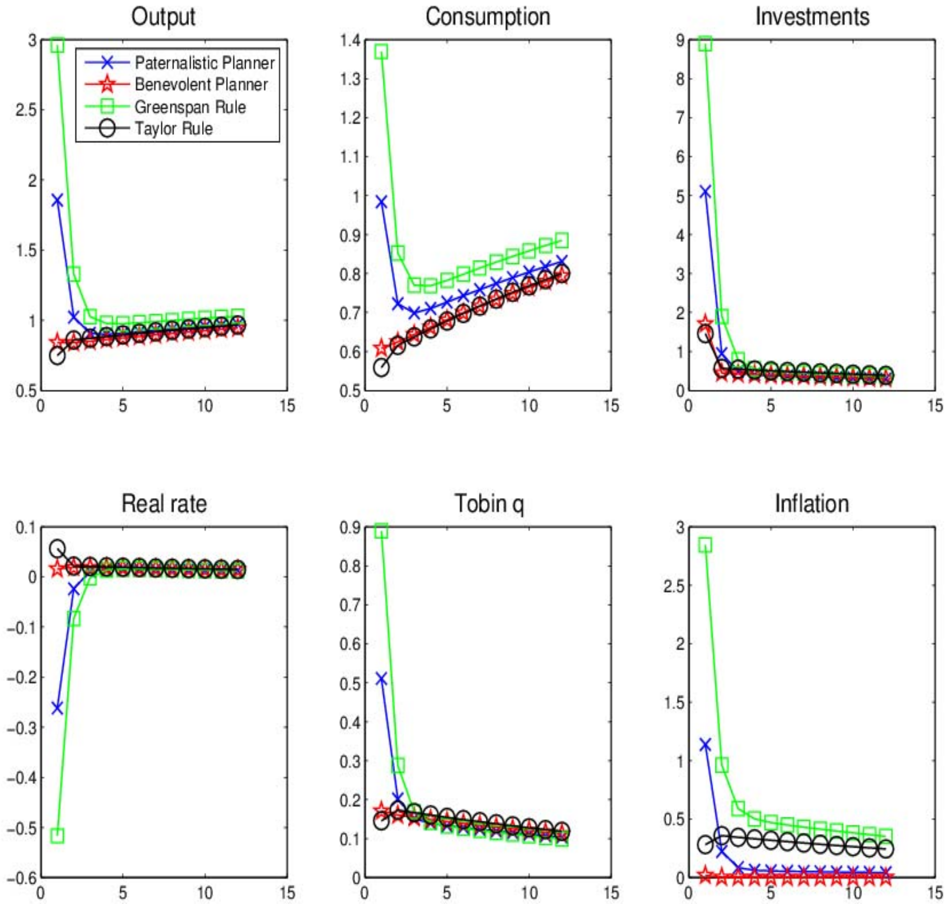

Figure 6: Impulse response of selected variables to a unitary permanent positive productivity shock under optimal policy and under different monetary policy rules for ψ =100.