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# Monetary policy, doubts and asset prices

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ABSTRACT

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



## 1. Introduction

After the 2007–2009 financial crisis, some argued that monetary policy had been too expansionary fuelling an asset price bubble.[1] This paper revisits 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. This issue is addressed 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]

The focus of this work is to study how the presence of doubts and ambiguity influences the characterization of optimal monetary policy. In our framework, agents do not trust the true probability distribution and make robust choices using a distorted probability distribution. In this environment, the objective of a policymaker caring about the agents might not be uniquely defined. This paper distinguishes 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. The policy conclusions change in a substantial and interesting way with respect to the rational-expectations model, when the policymaker is paternalistic, while they do not change for the benevolent policymaker.

With rational expectations, the welfare-maximizing policy following a productivity shock requires price stability. Moreover, average output cannot rise because it is too costly to increase inflation and therefore price dispersion.[3] In our

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[1] See for instance the discussion of Taylor (2007) and Section 5 in Greenspan (2010).

[2] Doubts and aversion to ambiguity are introduced using the framework of Hansen and Sargent (2005, 2008). See Barillas et al. (2009) for the ability of this framework to reproduce realistic values for the equity premium and the price of risk.

[3] For an overview of the main results of the literature see Benigno and Woodford (2005), Khan et al. (2003) and the recent review of Woodford (2010b).

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framework, the welfare-maximizing policy of the paternalistic policymaker is more accommodating and involves an increase in inflation following positive productivity shocks. Distorted beliefs enter the stochastic discount factor. This creates a wedge between average real marginal costs (or average output) and average inflation. The wedge is driven by the co-movements between the stochastic discount factor and the real marginal costs. Since the stochastic discount factor is negatively related to long-run productivity, it is countercyclical. If real marginal costs are procyclical, as following accommodating policies, average output can increase without much rise in average inflation and price dispersion. The side effect of this optimal policy is the increase in the volatility of quantities and a larger equity premium. 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 response through the channel described above, and the other towards a countercyclical policy because now ambiguity enters directly into the welfare objective of the policymaker.

Moreover, this paper shows 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. 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, the estimated Greenspan's policy is found to be too accommodative even from the perspective of our model.

The closest paper to our work is Karantounias (2013a), which analyzes a Ramsey problem but in the optimal taxation literature where, like in our paternalistic policymaker's case, the private sector distrusts the probability distribution of the model while the government fully trusts it. Our paper also analyzes a benevolent policymaker case.[4]

Woodford (2010a) 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 only the private sector that has doubts on the true model whereas the policymaker is fully knowledgeable even with respect to the doubts of the private sector. The different framework of Woodford (2010a) implies, in contrast to our results, that 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.[5] Dupor (2005) analyzes optimal monetary policy in a New-Keynesian model in which only the investment decisions are distorted by an ad hoc irrational expectational shock. In our framework, the distortions in the beliefs are instead the result of the aversion to model misspecification 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 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.[6]

The structure of the paper is the following. Section 2 presents the model. Section 3 describes the monetary policy problem. 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

Ambiguity and doubts are introduced in a standard New-Keynesian model using the approach developed by Hansen and Sargent (2005, 2008). Agents are endowed with one model, called the “reference” model, represented by a particular probability distribution. 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. Decision makers have to make their consumption and leisure decisions under model uncertainty. Preferences are described using the multiplier-preference approach of Hansen and Sargent (2005, 2008):

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

where $\beta$, with $0<\beta<1$, is the intertemporal discount factor, $C_t$ is a consumption index, which will be specified later, and $L_t$ is leisure. The objective (1) is composed of two terms. The first term represents the expected discounted value of the utility flows from consumption and leisure, where the non-negative martingale $G_t$ captures indeed the distortions with respect to the reference probability distribution. In the case in which $G_t=1$ at all times, there are no distortions. The martingale $G_t$ acts as a change of measure between the subjective model and the reference one. The second term, instead, represents discounted entropy, which measures the distance between the reference and the subjective probability distributions, where

[4] Besides the different focus of the two economic applications, the other subtle difference is in the approximation method. Whereas Karantounias (2013a) approximates around the stochastic no-distrust case for small deviations of the parameter identifying the dimension of the set of nearby model, our analysis approximates around a deterministic steady state allowing for even large deviations of the same parameter while bounding the maximum amplitude of the shocks.

[5] Recently, Adam and Woodford (2012) have casted Woodford's (2010a) analysis in a New Keynesian model with explicit microfoundations confirming previous results of Woodford (2010a), which were instead obtained adding model uncertainty to an already-linearized New-Keynesian model.

[6] See the papers cited in Ellison and Sargent (2012) and, among others, Dennis et al. (2009), Giannoni (2002), Leitemo and Soderstrom (2008), Rudebusch (2001), Tetlow (2007).

the martingale increment, $g_{t+1}$, is defined as $g_{t+1} \equiv G_{t+1}/G_t$ with $E_t g_{t+1} = 1$. The entropy is zero when the reference and subjective models coincide.

The agents choose consumption, labor and asset allocations, which will be specified later, to maximize the objective (1) under their budget constraint while at the same time an "evil" agent chooses the distorted probability distribution to disadvantage the decision maker by choosing $g_t$, and $G_t$, to minimize (1). How much entropy to allow between the subjective and reference models depends among other things on the parameter $\kappa$, with $\kappa > 0$, which is indeed a penalty parameter capturing the degree of ambiguity that the agent faces.[7] Higher values of $\kappa$ imply less fear of model misspecification, because this raises the cost of entropy in the minimization problem of the evil agent implying a choice for a less distorted probability distribution. When $\kappa$ goes to infinity the optimal level of entropy that minimizes (1) is zero. Therefore choices are made under rational expectations, since $g_t = G_t = 1$ at all times.

According to (1), the agents' decision problem in this economy is standard, on the one side, 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 an evil agent distorts their choices through the most unfavorable probability distribution given the weight entropy has in their preferences.

The max–min optimization of (1) 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 (1) into a non-expected recursive utility function of the form

$$V_t = (C_t L_t^{\eta})^{1-\beta}[E_t(V_{t+1})^{1-\psi}]^{\beta/(1-\psi)}, \tag{2}$$

where the coefficient $\psi$ is related to $\kappa$ through the following equation: $\psi \equiv 1 + 1/(\kappa(1-\beta)) \geq 1$. In particular, $\psi = 1$ corresponds now to the rational expectations model.[8] A further implication of the above minimization problem is that the martingale increment $g_{t+1}$ at the optimum can be written in terms of the non-expected recursive utility as

$$g_{t+1} = \frac{V_{t+1}^{1-\psi}}{E_t V_{t+1}^{1-\psi}}. \tag{3}$$

In the second step, using (2), the households' optimal allocation of consumption and leisure is derived subject to a flow budget constraint of the form

$$x_t Q_t^f + P_t(C_t + I_t) + T_t = x_{t-1}(Q_t^f + D_t) + W_t N_t + P_t^k K_t, \tag{4}$$

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 $t$, $Q_t^f$ the vector of prices of the financial assets while $D_t$ the vector of dividends; $P_t$ is the consumption-based price index. Finally $T_t$ represents government's lump-sum taxes, and $I_t$ investment. Given $K_t$ and $I_t$, next-period capital stock follows the law of motion:

$$K_{t+1} = \left(1 - \delta - \phi\left(\frac{I_t}{K_t}\right)\right)K_t + I_t, \tag{5}$$

where $\delta$, 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 it 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 Tobin's $q$.

The rest of the model is a standard New-Keynesian closed-economy model along the lines of King and Wolman (1996) and Yun (1996) where we abstract from monetary frictions. Aggregate consumption $C_t$ is given by a Dixit–Stiglitz aggregator of the continuum of consumption goods produced in the economy:

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

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

Households maximize expected utility (1) by choosing the sequences of consumption, capital, leisure and portfolio holdings under the flow budget constraint (4), the law of accumulation of capital (5) and an appropriate transversality condition. Standard optimality conditions imply the equalization of the marginal rate of substitution between consumption

[7] Hansen and Sargent (2005, 2008) show that the preference specification given by (1) 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. They also show that the two models can be aligned to imply the same equilibrium outcome. 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 Klibanoff et al. (2009).

[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, $\psi$ represents the risk-aversion coefficient, while in our framework $\psi$ is a measure of the degree of ambiguity.

and leisure to the real wage:

$$\eta\frac{C_t}{L_t}=\frac{W_t}{P_t}. \tag{6}$$

The set of first-order conditions with respect to consumption of each good $j$ delivers the consumption-based price index

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

where $P_t(j)$ is the price of the individual good $j$. Optimal portfolio choices imply the standard orthogonality condition between the stochastic discount factor and the asset return, $E_t\{g_{t+1}m_{t,t+1}r^f_{j,t+1}\}=1$, which includes also the change of measure, $g_{t+1}$, between the reference and the objective probability distributions. The real stochastic discount factor is defined as $m_{t,t+1}\equiv\beta C_t/C_{t+1}$ while the one-period real return on a generic asset $j$ is given by $r^f_{j,t+1}\equiv P_t(Q^f_{t+1}(j)+D_{t+1}(j))/(P_{t+1}Q^f_t(j))$. Moreover, the optimality condition with respect to capital can be written as an orthogonality condition of the form

$$E_t\{g_{t+1}m_{t,t+1}r^K_{t+1}\}=1, \tag{7}$$

where the real return on capital is defined by

$$r^K_{t+1}\equiv\frac{1}{q_t}\frac{P^k_{t+1}}{P_{t+1}}+\left[1-\delta-\phi\left(\frac{I_{t+1}}{K_{t+1}}\right)+\phi'\left(\frac{I_{t+1}}{K_{t+1}}\right)\frac{I_{t+1}}{K_{t+1}}\right]\frac{q_{t+1}}{q_t}, \tag{8}$$

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

$$q_t=\frac{1}{1-\phi'\left(\frac{I_t}{K_t}\right)}. \tag{9}$$

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 (8), 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.

### 2.1. Firms

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

$$Y_t(j)=(K_t(j))^\alpha(A_tN_t(j))^{1-\alpha}, \tag{10}$$

for each generic firm $j$ where $A_t$ represents a common labor-productivity shifter and $\alpha$, with $0<\alpha<1$, is the capital share. Given the households' optimal demand of each good $j$, a generic firm $j$ faces the following demand: $Y_t(j)=(P_t(j)/P_t)^{-\theta}Y_t$ where, in equilibrium, total output, $Y_t$, is equal to consumption and investment:

$$Y_t=C_t+I_t. \tag{11}$$

Households own firms which distribute profits in the forms of dividends. Given optimal portfolio choices, the real value of a generic firm $j$ is given by

$$\frac{Q^f_t(j)}{P_t}=E_t\left\{g_{t+1}m_{t,t+1}\frac{(D_{t+1}(j)+Q^f_{t+1}(j))}{P_{t+1}}\right\}, \tag{12}$$

where nominal dividends are defined as $D_t(j)=P_t(j)Y_t(j)-W_tN_t(j)-P^k_tK_t(j)$. Using (12) and the definition of dividends, the real value of a generic firm $j$ cum current dividend can be written as

$$\frac{Q^f_t(j)+D_t(j)}{P_t}=E_t\left\{\sum_{T=t}^{\infty}\frac{G_T}{G_t}m_{t,T}\left[\frac{P_T(j)Y_T(j)-W_TN_T(j)-P^k_TK_T(j)}{P_T}\right]\right\},$$

where $m_{t,t}=1$. Firms choose prices, capital and labor to maximize the firm's value cum current dividend. It should be further noted that the distortion in beliefs of the households translates into the same distortions in the firms' problem through asset prices. Cost minimization under the production function (10) implies that total costs are linear in current output:

$$W_tN_t(j)+P^k_tK_t(j)=\left(\frac{W_t}{A_t(1-\alpha)}\right)^{1-\alpha}\left(\frac{P^k_t}{\alpha}\right)^\alpha Y_t(j)\equiv S_tY_t(j),$$

where $S_t$ denotes the real marginal cost, and that the capital-to-labor ratio is equalized across firms:

$$\frac{K_t(j)}{N_t(j)} = \frac{\alpha}{1-\alpha}\frac{W_t}{P_t^k}. \tag{13}$$

Firms are subject to price rigidities as in the Calvo mechanism. In particular, at each point of time, firms face a constant probability $(1-\gamma)$, with $0<\gamma<1$, of adjusting their price, which is independent of the relevant state for setting prices. Firms, which can adjust their price $P_t(j)$ in period $t$, set it by maximizing the present-discounted value of the firm's profits cum current dividend considering that prices set at time $t$ will last until a future time $T$ with probability $\gamma^{T-t}$. The following aggregate-supply equation results in

$$\frac{1-\gamma \Pi_t^{\theta-1}}{1-\gamma} = \left(\frac{F_t}{Z_t}\right)^{\theta-1}, \tag{14}$$

in which the gross inflation rate is defined by $\Pi_t \equiv P_t/P_{t-1}$, and the variables $Z_t$ and $F_t$ are given by the following expressions:

$$Z_t \equiv \frac{\theta}{\theta-1} E_t\left\{\sum_{T=t}^{\infty}(\beta\gamma)^{T-t}\frac{G_T}{G_t}\left(\frac{P_T}{P_t}\right)^{\theta}\frac{Y_T}{C_T}S_T\right\}, \tag{15}$$

$$F_t \equiv E_t\left\{\sum_{T=t}^{\infty}(\beta\gamma)^{T-t}\frac{G_T}{G_t}\left(\frac{P_T}{P_t}\right)^{\theta-1}\frac{Y_T}{C_T}\right\}. \tag{16}$$

### 2.2. Equilibrium

In equilibrium, aggregate output is used for consumption and investment as in (11). Financial market equilibrium requires that households hold all the outstanding equity shares and that all the other assets are in zero net supply. Moreover $K_t = \int_0^1 K_t(j)\,dj$ and $N_t = \int_0^1 N_t(j)\,dj$. In particular, equilibrium in the labor market implies

$$N_t = \int_0^1 N_t(j)\,dj = \frac{1}{A_t^{1-\alpha}}\left(\frac{N_t}{K_t}\right)^{\alpha} Y_t \Delta_t, \tag{17}$$

where $\Delta_t$ is a measure of price dispersion that follows the law of motion:

$$\Delta_t = \gamma\pi_t^{\theta}\Delta_{t-1} + (1-\gamma)\left(\frac{1-\gamma\Pi_t^{\theta-1}}{1-\gamma}\right)^{\theta/(\theta-1)}. \tag{18}$$

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 $\{C_t, Y_t, K_t, N_t, I_t, F_t, Z_t, P_t, P_t^k, W_t, q_t, \Delta_t, g_t, G_t, V_t\}$ such that Eqs. (2), (3), (5), (6), (7), (9), (11), (13), (14), (15), (16), (17), (18) hold, considering the definitions of the following variables $m_{t,t+1}$, $r_t^k$, $L_t$, $\Pi_t$, which are given in the text, and given that $G_{t+1} = g_{t+1}G_t$ with $G_{t_0} = 1$.

## 3. Optimal policy problem

This section studies the optimal policy problem. In the framework of this paper 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 problem the objective of policy coincides with the expected utility of the households under rational expectations. In our framework, things are more complicated because agents form expectations under the distorted probability distribution while data are drawn from the reference probability distribution. Moreover, as discussed in Barillas et al. (2009), model uncertainty might be just in the head of the agents: they have complete knowledge of the reference probability distribution but simply they do not trust it. Therefore, the preferences described in (2) represent more a way to handle decisions in an ambiguous world rather than the utility agents are getting. Indeed, at the end, states of nature will be realized through the reference probability distribution. This opens the possibility for 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 (1) or, equivalently, by (2). A paternalistic policymaker instead commits to maximize the present discounted value of the utility flows

$$E_{t_0}\sum_{t=t_0}^{\infty}\beta^{t-t_0}[\ln C_t + \eta \ln L_t], \tag{19}$$

where expectations are taken under the reference probability distribution, which governs the realization of the states of nature. The objective (19) is not only 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 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.[10]

We are interested in characterizing optimal policy under commitment from a "timeless perspective", as discussed among others by Benigno and Woodford (2012). Our solution method is to consider the set of non-linear first-order conditions of the two optimal policy problems and proceed as follows. First, optimal policy in the non-stochastic steady state is evaluated. Second, using standard perturbation techniques, first and second-order approximations to the non-linear stochastic first-order conditions, characterizing the optimal policy problem (discussed above), are taken around the optimal steady state, and the resulting equilibrium allocation is studied.[11]

The structural parameters of the model are calibrated consistently with existing results in the macroeconomic literature. It is set to $\alpha = 0.36$, which corresponds to a steady-state share of capital income equal to roughly 36 percent, and $\delta = 0.025$, which implies a rate of capital depreciation equal to 10 percent at annual rates. In addition, the coefficient of the demand elasticity with respect to prices, $\theta$, is set equal to 6, implying a steady-state price markup of 20 percent. The parameter governing the frequency of price adjustment is set equal to $\gamma = 0.6$ to match the estimates of Klenow and Kryvtsov (2008). The second-derivative of the adjustment-cost function $\phi(\cdot)$ evaluated at the steady state is set in such a way that $1/\overline{\phi}'' = 0.25$, which corresponds to the steady-state elasticity of the investment-to-capital ratio with respect to Tobin's $q$ estimated by Jermann (1998). The parameter $\eta$ is set equal to 0.45 to obtain a steady-state Frisch elasticity of labor supply of 1.8, which is in the range of standard values used in the macro literature. The following random-walk process for productivity is assumed:

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

where $\varepsilon_{t+1}$ has zero mean and standard deviation $\sigma$, and $\zeta$ is a drift in productivity. Moreover, it is set $\sigma = 0.012$ and $\zeta = 0.003$ to match respectively the volatility and the mean of U.S. quarterly total factor productivity growth estimated by Fernald (2012). The model is consistent with a balanced-growth path, and therefore a stationary representation can be obtained by re-scaling the appropriate variables through the level of productivity. Optimal policy is studied for different values of the parameter $\psi \in \{1, 50, 100\}$. 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 $\beta = 0.993$, implying a yearly real interest rate of three percent in the non-stochastic steady state.

## 4. Optimal policy: results

Fig. 1 shows the impulse responses of selected variables to a one standard deviation positive shock to productivity under different values of the parameter $\psi$ for the benevolent policymaker, while Fig. 2 shows the results of the same experiment for the paternalistic policymaker.

The case $\psi = 1$ corresponds to the benchmark model of rational expectations where, as established in the literature, price stability is the optimal policy. Benevolent and paternalistic policymakers' outcomes coincide. 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, Tobin's $q$ and therefore investment increase on impact.

When agents face ambiguity, $\psi > 1$, the optimal policies run by a benevolent or a paternalistic policymaker are quite different. There are two main results. First, the equilibrium outcome implied by the benevolent policymaker is similar to the benchmark rational-expectations model, and this is true for any degree of model uncertainty. As shown in Fig. 1, there are marginal deviations from a policy of price stability.

Second, the policy chosen by the paternalistic policymaker changes quite substantially and the higher is the degree of model uncertainty. As shown in Fig. 2, the optimal policy of the paternalistic policymaker becomes very procyclical. Inflation increases on impact and then steadily declines toward zero. The higher this increase, the higher is the degree of model uncertainty. Nominal interest rates become more volatile: they decrease first and then rise. In the short run, the real interest rate falls to push consumption and output even to overshoot their long-run levels. Tobin's $q$ jumps at higher levels leading to a larger change in investment. As $\psi$ increases, optimal policy under the paternalistic policymaker becomes more and more procyclical to the technology shock. Moreover, the higher the $\psi$ is, the higher is the volatility of the return on equity and capital and the price of equity and capital.

[9] In an optimal taxation problem, Karantounias (2013a) focuses on this case, calling it the Ramsey policymaker. Karantounias (2013b), in the same environment, considers a policymaker who also expresses doubts on the "reference" probability distribution.

[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.

[11] See the online appendix for further details.

[12] The 5.5% equity premium is obtained under an interest rate rule which requires the risk-free nominal interest rate to evolve according to Eq. (22) that will be described later in the text. Parameters of the policy rule are set to values estimated by Clarida et al. (2000): $\rho_r = 0.93$, $\phi_\pi = 2.15$ and $\phi_x = 0.79$.

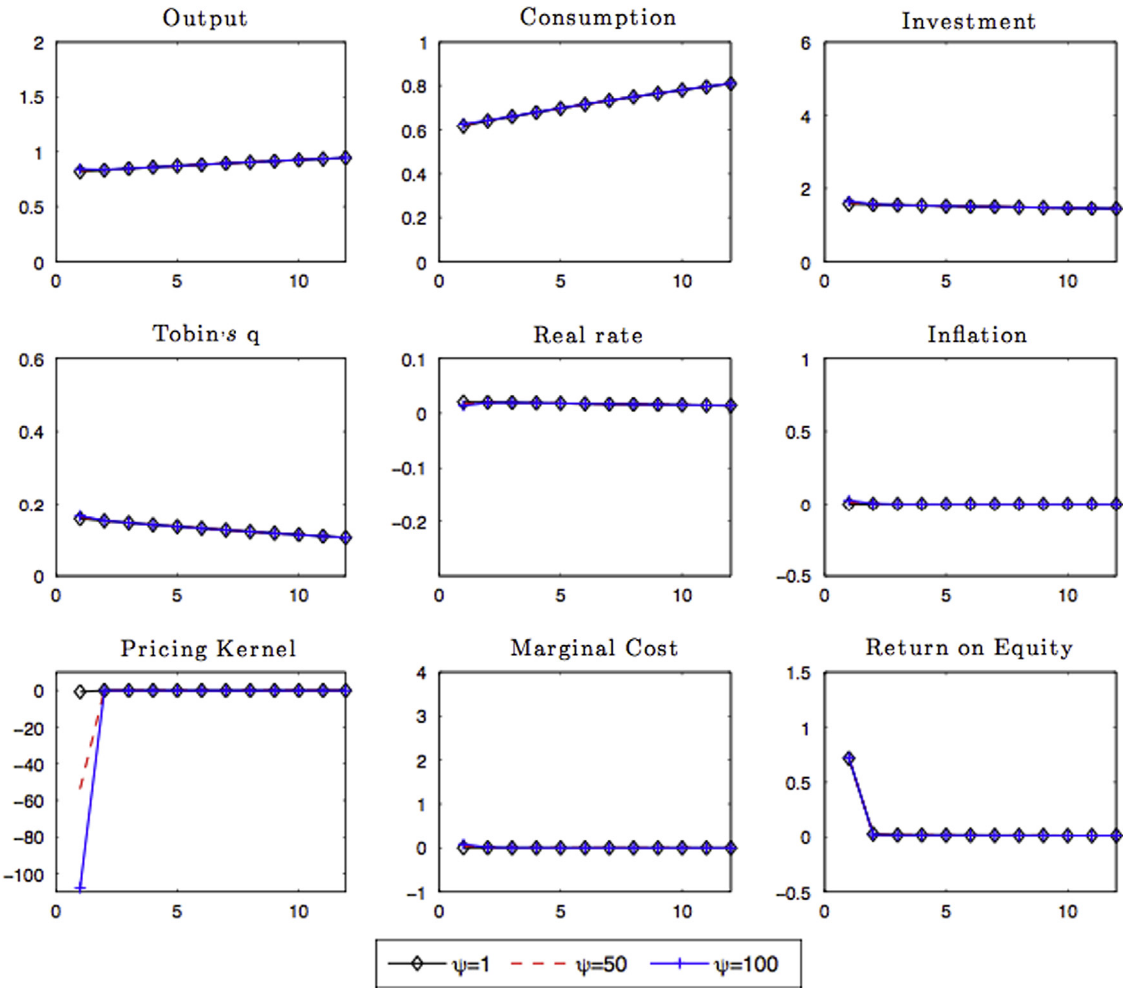


**Fig. 1.** Impulse responses at optimal policy under the "benevolent" policymaker. *Note*: Impulse responses of selected variables for different values of the degree of ambiguity aversion $\psi$ to a one standard deviation positive productivity shock of size 1.2%. Variables are expressed in % deviations from the non-stochastic steady state.

Table 1 reports estimates of several statistics of interest, through a second-order approximation of the equilibrium dynamics at the optimal policy, for both the paternalistic and benevolent policymakers when $\psi = 100$. The variables of interest are the averages of output (scaled by productivity), hours worked, markup, price dispersion and inflation, as well as the one-period equity premium.

Since there is a unit root in the system of equations associated with the optimal policy problem, those statistics of interest are not necessarily well defined using unconditional operators.[13] Thus we proceed in the following way. Starting from the non-stochastic steady-state values, two parallel economies are simulated for $n$ quarters: one economy under the paternalistic optimal policy and the other under the benevolent optimal policy. It should be noted that the steady state of quantity and prices is the same across the two cases and that also the realizations of productivity shocks are the same by construction of the experiment. The number of quarters is set at $n = 300$, the first 100 simulations are not considered and the statistics of interest are computed using the remaining 200 periods corresponding to 50 years of data. This exercise is repeated 10,000 times. Table 1 reports the mean (and standard deviation in parenthesis) of the statistics just described computed across the 10,000 repetitions. The purpose of this exercise is to compare the equilibrium outcomes under the paternalistic and benevolent policies of otherwise identical economies. The standard deviations in parenthesis provide information on the stability of the statistics computed over the 200 periods, and thus an assessment of the relevance of the unit root.

First notice that average output, hours worked and equity premium are larger than their non-stochastic steady state values, under both policies. This is due to the impact of volatility on equilibrium outcomes. Second, most importantly, the

[13] See the online appendix for details.

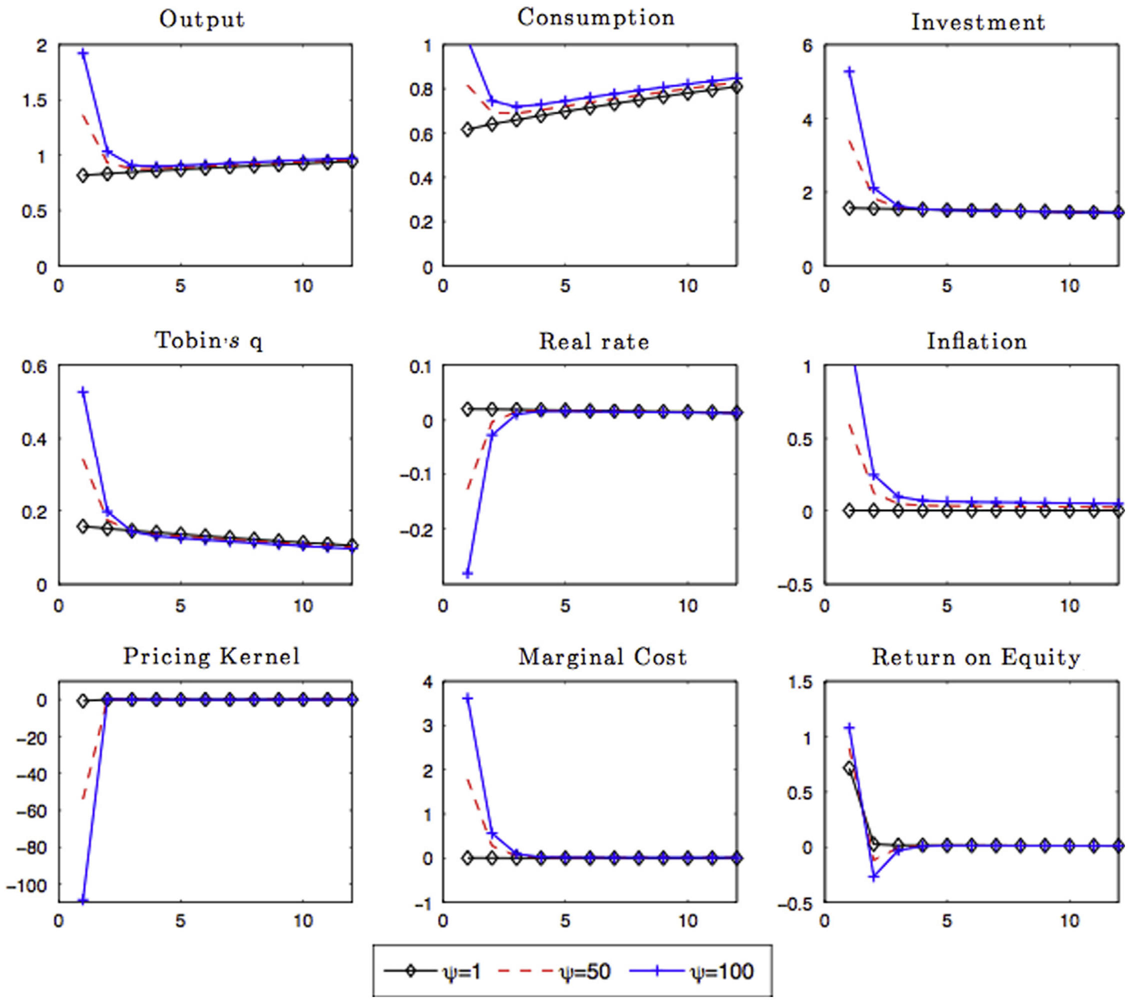


**Fig. 2.** Impulse responses at optimal policy under the "paternalistic" policymaker. *Note*: Impulse responses of selected variables for different values of the degree of ambiguity aversion $\psi$ to a one standard deviation positive productivity shock of size 1.2%. Variables are expressed in % deviations from the non-stochastic steady state.

paternalistic policymaker increases average output more than the benevolent policymaker by reducing substantially the average markup as already discussed.

In particular, the average markup under the paternalistic policymaker decreases to 15.57% from 20% in steady-state, while under the benevolent policymaker the average markup barely changes with respect to steady state. Surprisingly, in both cases, the average inflation is roughly zero. In fact, the price dispersion is marginally larger under the paternalistic policymaker's case, reflecting the higher volatility of inflation, but still quite low. As a result of the more procyclical policy, the equity premium under the paternalistic policymaker is 5.28% on a yearly basis when $\psi = 100$, against 3.12% under the benevolent policymaker. 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 models present in the literature along the direction of matching also financial data. This is not really a novelty for partial equilibrium analysis that has explained the equity premium through doubts, as Barillas et al. (2009). However, an important insight from our general equilibrium analysis is that monetary policy can play a significant role for the size of the risk premia.

The next section argues that the ability of the paternalistic policymaker to increase average output without much costs in terms of higher price dispersion comes by exploiting asset-price movements, which indeed generate higher equity premia.

## 5. The role of model uncertainty 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

**Table 1**
Means of selected variables under alternative policies.

| Selected Statistics | Benevolent policymaker | | Paternalistic policymaker | |
|---|---|---|---|---|
| Avg. output[a] | 9.13 | (0.62) | 11.34 | (0.50) |
| Avg. hours | 1.71 | (0.15) | 3.71 | (0.31) |
| Avg. markup | −0.04 | (0.16) | −4.43 | (0.44) |
| Avg. dispersion | 0.00 | (0.00) | 0.18 | (0.02) |
| Avg. inflation[b] | 0.24 | (0.08) | 0.11 | (0.56) |
| Equity premium[b] | 3.12 | (0.48) | 5.28 | (1.28) |
| Std. output | 1.48 | (0.02) | 2.21 | (0.13) |
| Std. inflation[b] | 0.12 | (0.00) | 4.86 | (0.49) |

*Note*: Means of selected variables in % log-deviation from the non-stochastic steady state when $\psi = 100$. Standard errors in parenthesis. Markup denotes the gross markup on marginal cost. Dispersion is measured by $\Delta_t$. The equity premium is measured by the realized premium on equity $r_t^f - r_t$. where $r_t$ denotes the risk free real interest rate.

[a] Output is scaled by productivity, i.e. $Y_t/A_{t-1}$.

[b] At annual rates.

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, nominal price rigidity, monopolistic competition, capital adjustment costs, and distorted beliefs, which indeed originate from doubts and ambiguity. The nature of each of the four distortions is discussed while, borrowing from the analysis of Khan et al. (2003), it is shown how each distortion can be selectively eliminated 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. Therefore, to remove the aggregate implications of steady-state markup, a subsidy to firms' sales can be used such that $\tau^s = \theta/(\theta-1)-1$.

*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 Eqs. (17)–(18), where the natural measure of this distortion is given by $\Delta_t$: 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, a level of government spending, $\Upsilon_t$, is set each period in such a way that $\Upsilon_t = (1/\Delta_t - 1/\overline{\Delta})K_t^{\alpha}(A_t N_t)^{1-\alpha}$, where $\overline{\Delta}$ is the level of price dispersion in the non-stochastic steady state.[14]

*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 Tobin's $q$ in Eq. (9). 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, the fiscal authority could subsidize investments in physical capital with a subsidy given by $\tau_t = \phi(I_t/K_t)K_t$.

*Beliefs' distortion*: 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 Jensen's inequality, can be written as

$$E_t\left[\hat{r}_{t+1}^K\right] - \hat{r}_t + \tfrac{1}{2}Var_t\left[\hat{r}_{t+1}^K\right] \simeq -Cov_t\left[\hat{m}_{t,t+1}, \hat{r}_{t+1}^K\right] - Cov_t\left[\hat{g}_{t+1}, \hat{r}_{t+1}^K\right],$$

where variables with hats denote deviations from the steady state, and $\hat{r}_t$ denotes the risk free real interest rate. The distortion in the beliefs adds an additional term to the premium on the capital return, which now depends on the covariance between the one period ahead return on capital, $\hat{r}_{t+1}^K$, and innovation in 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 the long-run level of technology and therefore negatively correlated with $\hat{g}_{t+1}$. To see why $\hat{g}_{t+1}$ depends negatively on the long-run level of technology, take a first-order approximation of Eqs. (2) and (3) and assume that $\beta$ is close to unitary value, then $\hat{g}_{t+1}$ can be approximated by $\hat{g}_{t+1} \simeq -(\psi-1)\ \varepsilon_{t+1}$.[15] 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]

[14] Government spending is assumed to be 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.

[15] See the online appendix for a derivation.

[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 influence returns and therefore covariances.

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 using Eqs. (15)–(16), Eq. (14) can be written as

$$\left(\frac{1-\gamma\Pi_t^{\theta-1}}{1-\gamma}\right)^{1/(\theta-1)} = \frac{\theta}{\theta-1}\frac{\sum_{T=t}^{\infty}(\beta\gamma)^{T-t}\{E_t[\Pi_{t,T}^{\theta-1} S_T]+Cov_t[\Pi_{t,T}^{\theta-1}S_T,\ G_T/G_t]\}}{\sum_{T=t}^{\infty}(\beta\gamma)^{T-t}\{E_t[\Pi_{t,T}^{\theta}]+Cov_t[\Pi_{t,T}^{\theta},\ G_T/G_t]\}}, \tag{20}$$

where $\Pi_{t,T}$ is the inflation rate between periods $t$ and $T$. Eq. (20) makes clear that there exists a positive relationship between inflation and the present discounted value of expected real marginal cost, evaluated under the reference probability measure. The distortion in beliefs affects this relationship through the covariance terms on the right-hand side of (20). If, for given inflation, the conditional covariance at time $t$ between the realizations at each time $T>t$ of innovation in beliefs ($G_T/G_t$) and marginal cost ($S_T$) is negative (positive), the average marginal cost ($E_t[S_T]$) at each $T>t$ is higher (lower) than it would be without distortion in beliefs. This implies that, for given inflation, average markup is lower (higher) than it would otherwise be in the absence of distorted beliefs, if the conditional covariance at time $t$ between $G_T/G_t$ and $S_T$ is on average negative (positive).

To remove each of the two distortions originating from subjective beliefs, fiscal instruments can be used to 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, $\tau_{t+1}^K$, 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 Eq. (12) to correct for distorted beliefs in the value of the firm, which affects price setting decisions.

### 5.1. Results

Fig. 3 presents 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

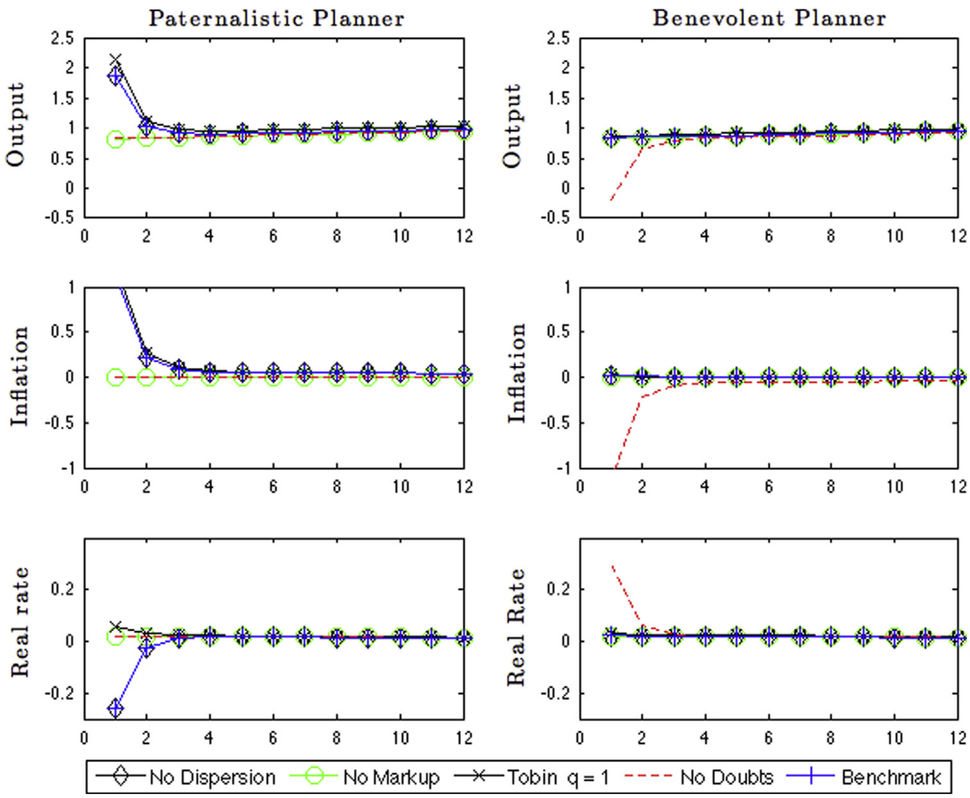


**Fig. 3.** Impulse responses at optimal policy under alternative model specifications. *Note*: Impulse responses of selected variables to a one standard deviation positive productivity shock of size 1.2%, under the optimal policy of the “paternalistic” policymaker (left column) and of the “benevolent” policymaker (right column). Variables are expressed in % deviations from the non-stochastic steady state. Each line represents one particular specification of the model. “Benchmark” refers to the model with all distortions in place. In the remaining specifications we remove one distortion at a time: “No Dispersion” refers to eliminating the relative-price distortion; “No Markup” refers to eliminating the steady-state mark-up distortion. “No Doubts” refers to eliminating the distortions in the beliefs of the private sector; “Tobin $q=1$” refers to eliminating the adjustment cost in capital.

(on the left column) for the various cases in which each distortion is removed in turn. In the figure the parameter $\psi$ is fixed at $\psi = 100$.

Starting with the paternalistic policymaker, once either the monopolistic-competition distortion or the beliefs' distortion is eliminated, it is possible to obtain that the optimal policy is to stabilize inflation to zero as in rational-expectations case, i.e. $\psi = 1$. Therefore, the interaction between these two distortions has to explain why in the general case of $\psi > 1$ the paternalistic policymaker chooses a more procyclical response of output and inflation following a productivity shock. Given the monopolistic-competition distortion, output and real marginal cost are too low. The policymaker can affect average output by influencing the co-movements between variables but cannot move output in a systematic way, since commitment is assumed.[17] In particular, the policymaker could increase the average real marginal cost and output at the cost of raising price dispersion. As shown in the literature, in the rational-expectations case, it is relatively too costly to create inefficient price dispersion so that the trade-off between price dispersion and average output is too steep to correct for the distortions due to monopolistic competition.

Instead, with model uncertainty, there is an additional channel through which the decision maker can affect average markup, and thus average output. When compared to the standard channel discussed above, this novel channel allows us to increase average output at the cost of less price dispersion. This channel works by exploiting the co-movements between distorted beliefs and real marginal costs. In particular, as shown in Eq. (20), by making real marginal cost, $S_T$, to co-move negatively with the distortions in beliefs, $G_T/G_t$, the expected real marginal costs can be higher and therefore markups lower on average, for a given path of inflation.[18] The more negative the covariance between marginal cost and distorted beliefs, the lower the markups on average. From this perspective, the resulting higher equity premia and volatility of the stochastic discount factor are the mirror images of the mechanisms at work to achieve an optimal monetary policy.

Next the focus is on the optimal policy under the benevolent policymaker. The impulse responses change substantially from the full-distortion case only when we remove the distorted beliefs, while keeping (2) as the objective to be maximized. Indeed, the result that the benevolent policymaker aims always at a policy of price stability, as in the rational-expectations model, hinges on the fact that the distortions in the beliefs of the policymaker and those of the private sector are perfectly aligned.

To understand this, consider that the objective function (2) of the benevolent policymaker can be written back as (1), where $G_t$ follows the martingale process in which the martingale increment, $g_t$, is optimally chosen and given by (2) and (3). Under these constraints, the objective function (1) is indeed equivalent to (2). 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 (1) is quasi-independent of policy. This means that the objective of the benevolent policymaker can be approximated by

$$\sum_{t=t_0}^{\infty} \beta^{t-t_0} \tilde{E}_{t_0}[U(C_t, L_t)] = \sum_{t=t_0}^{\infty} \beta^{t-t_0} E_{t_0}[U(C_t, L_t)] + \sum_{t=t_0}^{\infty} \beta^{t-t_0} Cov_{t_0}[U(C_t, L_t), G_t], \tag{21}$$

where the distorted-expectation operator is such that $\tilde{E}_{t_0}[U(C_t, L_t)] = E_{t_0}[G_t U(C_t, L_t)]$. Using this observation, it can be further shown that the optimal policy problem (objective and constraints) can be written in terms of the distorted expectation operator. It follows that this problem will be exactly equivalent to that of the standard 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.

Consistent with the discussion above, Fig. 3 shows that, after removing the distortions in beliefs from the constraints of the policy problem, the benevolent policymaker would like to produce a countercyclical response of output and inflation following the productivity shock. While distorted beliefs do not affect equilibrium allocations, they still have an impact on welfare in this case, as shown in (21). For instance, suppose that the planner was following a policy of zero inflation then the covariance between the martingale, $G_t$, and the utility flow, $U(C_t, L_t)$ would be negative in (21), as the utility flow increases following a positive innovation in productivity while the martingale depends negatively on the productivity shock. The policymaker can improve welfare through a more countercyclical policy than the constant inflation policy so as to reduce the negative co-movement between $U(C_t, L_t)$ and $G_t$.

Thus, the difference in the optimal policy of the benevolent policymaker relative to the one of the paternalistic policymakers is explained by the incentive towards a more countercyclical monetary policy coming directly from the impact of beliefs distortions into the welfare objective of the benevolent policymaker. This channel offsets the incentives towards a more procyclical policy that come from the impact of distorted beliefs in the set of constraints to the policy problem.

## 6. Greenspan, a paternalistic policymaker in our model?

In this section Alan Greenspan's policy is evaluated from the perspective of the optimal policy implied both by the paternalistic and benevolent policymakers. Greenspan's policy is modeled through an interest rate rule for the risk-free

[17] In a second-order approximation of the model, the average value of a variable depends on second-order terms. The policymaker can act on these terms to affect the average value of output and other variables.

[18] In Eq. (20), the terms $E_t[\Pi_{t,T}^{\theta-1} S_T]$ can be lowered without increasing inflation because the covariance terms on the numerator of the right-hand-side of the equation are negative.

nominal interest rate $1+i_t$:

$$\ln\left(\frac{1+i_t}{1+\bar{\imath}}\right)=\rho_r\ln\left(\frac{1+i_{t-1}}{1+\bar{\imath}}\right)+(1-\rho_r)\left(\phi_\pi\ln\frac{\Pi_t}{\overline{\Pi}}+\phi_y\ln\frac{Y_t}{Y_t^*}\right), \tag{22}$$

where $1+\bar{\imath}$ and $\overline{\Pi}$ are steady-state values of the respective variables and $Y_t^*$ is potential output, defined as the equilibrium level of output with flexible prices and no capital-adjustment costs. Eq. (22) is estimated on the sample period corresponding to Greenspan as chairman of the Federal Reserve, 1987:3-2006:1.[19] It is obtained that $\rho_r=0.9$, $\phi_\pi=0.99$ and $\phi_y=0.75$. The model is solved under the estimated policy rule (22) at a degree of model uncertainty $\psi=100$.

In Fig. 4 the impulse responses of selected variables are plotted under Greenspan's policy against the responses obtained under the optimal policy of both the benevolent and paternalistic policymakers in our model. Notice that the impulse responses under the classic Taylor Rule, i.e. the interest rate rule (22) evaluated at $\rho_r=0$, $\phi_\pi=1.5$ and $\phi_y=0.5$, would yield very similar impulse responses to the ones obtained under the policy chosen by the benevolent policymaker, and are therefore omitted. In fact, optimal policy under the benevolent policymaker is very close to a policy of inflation targeting in our model. As Fig. 4 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's policy was perhaps too procyclical with respect to productivity shocks. For instance, output under Greenspan's policy rises on impact by about 50% more than it should when compared to the optimal policy of the paternalistic policymaker. In contrast, output under benevolent policymaker 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 the 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

Doubts are introduced into a standard New-Keynesian monetary model. 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 optimal policy is studied 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, a paternalistic policymaker should have a more procyclical policy response with respect to productivity shocks, inflating the equity premium. The larger the departure, 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, households and firms share the same degree of doubts. Households' doubts are reflected in Arrow–Debreu prices and those are used to evaluate both the 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, the only disturbance affecting the economy is a productivity shock. Results would not change with stationary markup shocks. Indeed, doubts and ambiguity aversion are reflected in fears of bad news regarding long-run consumption on which transitory markup shocks, contrary to persistent productivity shocks, do not have much influence. 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. The analysis of the intermediate cases is left to future work. 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, the analysis is kept the closest as possible to the benchmark New-Keynesian model to show how a small departure from that 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.

[19] The rule (22) has been estimated with the method of instrumental variables suggested by Clarida et al. (2000). Instruments are the four lags of inflation, output gap, the growth rate of money supply, commodity price inflation and the spread between the long-term bond rate and the 3-month Treasury Bill rate. Data are taken from the dataset of the Federal Reserve Bank of St. Louis.

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

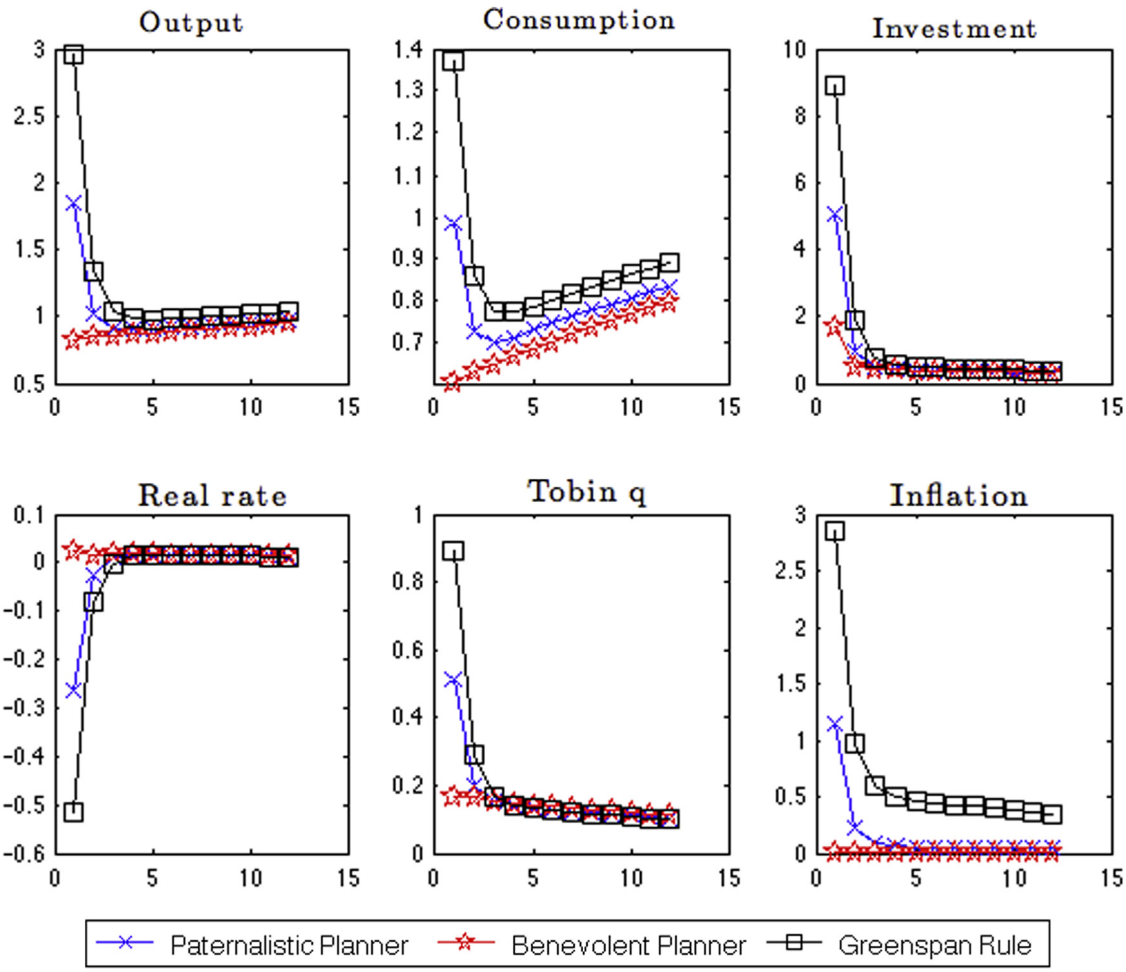


**Fig. 4.** Impulse responses under alternative monetary policies. *Note*: Impulse response of selected variables to a one standard deviation positive productivity shock of size 1.2%, under alternative monetary policies at $\psi = 100$. "Paternalistic Planner" refers to the policy that maximizes the "paternalistic" policymaker objective; "Benevolent Planner" refers to the policy that maximizes the "benevolent" policymaker objective; "Greenspan Rule" refers to an interest rate rule estimated on data from the period of Greenspan's tenure as Federal Reserve chairman. Variables are expressed in % deviations from the non-stochastic steady state.

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## Appendix A. Supplementary data

Supplementary data associated with this paper can be found in the online version at http://dx.doi.org/10.1016/j.jmoneco.2014.02.004.

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