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Recent fiscal interventions have raised concerns about US public debt, future distortionary tax pressure, and long-run growth potential. We explore the long-run implications of public financing policies aimed at short-run stabilization when: (i) agents are sensitive to model uncertainty, as in Hansen and Sargent (2007), and (ii) growth is endogenous, as in Romer (1990). We find that countercyclical deficit policies promoting short-run stabilization reduce the price of model uncertainty at the cost of significantly increasing the amount of long-run risk. Ultimately these tax policies depress innovation and long-run growth and may produce welfare losses.

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The Market Price of Fiscal Uncertainty[☆]

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Abstract

Recent fiscal interventions have raised concerns about US public debt, future distortionary tax pressure, and long-run growth potential. We explore the long-run implications of public financing policies aimed at short-run stabilization when: (i) agents are sensitive to model uncertainty, as in Hansen and Sargent (2007), and (ii) growth is endogenous, as in Romer (1990). We find that countercyclical deficit policies promoting short-run stabilization reduce the price of model uncertainty at the cost of significantly increasing the amount of long-run risk. Ultimately these tax policies depress innovation and long-run growth and may produce welfare losses.

Keywords: Robustness, Endogenous Growth, Fiscal Uncertainty

1. Introduction

The current situation of fiscal stress has increased doubts about the future dynamics of US public debt. As shown in figure 1, US debt-output ratio projections from the Congressional Budget Office (CBO) span an increasingly wide range over the next decades, leaving room for substantial uncertainty. Given the distortionary nature of the main tax instruments used to finance the government budget, it is natural to wonder to what extent such uncertainty can affect consumption and investment decisions and, more broadly, the long-term prospects of the economy. In a nutshell, figure 1 raises the question of how the formation of beliefs and revisions about the likelihood of different fiscal scenarios could alter economic outcomes.

In this paper, we study the impact of fiscal policy on long-term growth when agents are uncertain about the probability distribution of future fiscal prospects. More precisely, we assume that agents fear model uncertainty as in Hansen and Sargent (2007) and are willing to optimally slant probabilities toward the worst-case scenario. We examine the implications of worst-fiscal-scenario beliefs in a stochastic version of the Romer (1990) endogenous growth model that assumes that the government finances exogenous expenditures using both debt and distortionary taxes on labor income. By doing so, we are able to analyze the link between fear of misspecification of future fiscal distortions, short-run fluctuations, and—in contrast to several other studies—long-term growth prospects.

Using this robust control approach, we obtain the following results. First, as aversion to model uncertainty becomes more severe, the distorted expected value of taxes is increasingly higher than the true value. This implies that
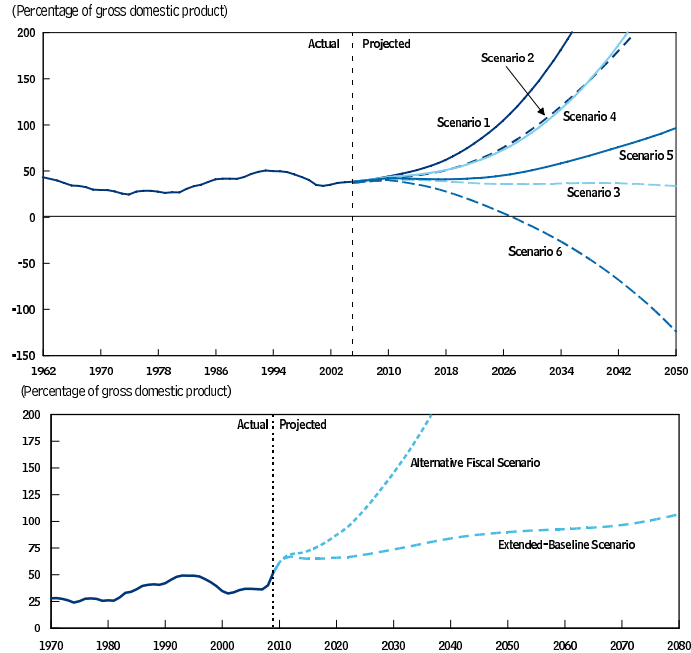
Figure 1: CBO Projections of Future US Debt

Notes - This Figure shows Federal Debt Held by the Public under CBO's Long-Term Budget Scenarios. The top panel refers to the CBO's Long-Term Budget Outlook issued in 2005. The bottom panel is based on the 2010 outlook. See `www.cbo.gov`.

agents face stronger expected tax distortions and have less incentive to work relative to the case in which beliefs are undistorted. In our setting with endogenous growth, a lower labor supply results in a smaller long-term growth rate of consumption and produces substantial welfare losses.

Following the methodology of Barillas et al. (2009), we link welfare losses associated with worst-case beliefs to the market price of model uncertainty, which in our model is linked with the *market price of fiscal uncertainty*. We differ from Barillas et al. (2009) in that we focus on fiscal policy in a model with endogenous growth.

In order to show that there exists a significant difference between fiscal risk and fiscal uncertainty, we examine the implications of commonly observed countercyclical fiscal policies seeking to stabilize short-run fluctuations by means of public debt. Using exogenously specified fiscal policy rules, we show that when growth is endogenous, financing policies that are welfare enhancing under time-additive CRRA preferences can turn into a source of relevant welfare losses under aversion to model uncertainty.

Intuitively, tax cuts stabilize the economy in the short run upon the realization of adverse exogenous shocks. This reduction in short-run consumption risk is a desirable benefit for both risk- and model uncertainty-averse agents. However, the subsequent financing needs associated with long-run budget balancing produce more persistent dynamics for long-run distortionary taxation. In contrast to agents with CRRA preferences, agents with preferences for robustness are averse to such long-run risks. In our endogenous growth model, countercyclical fiscal policies end up depressing the present value of future cash flows and hence the incentive for long-run growth.

We discipline the aversion to model uncertainty to reproduce key features of both US consumption and wealth-consumption ratios as measured by Lustig et al. (2010) and Alvarez and Jermann (2004) and we find that growth losses outweigh the benefits of short-run stabilization, as opposed to the time-additive preferences case. Basically, counter-cyclical deficit policies reduce uncertainty by reducing short-run volatility, but at the cost of increasing the amount of long-run risk embedded in innovative products' cash flows. Stabilization comes at the cost of undermining long-run growth.

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1.1. Related Literature

Karantounias (2011) and Karantounias (2012) consider fiscal policy in a robust setting. In contrast to us, they focus on optimal Ramsey taxation and abstract from endogenous growth, which is the key channel of our welfare analysis. These papers provide theoretical foundations for robust optimal fiscal policy, but they do not feature any trade-off between stabilization and long-run growth arising from the incentives to innovate.

More broadly, our paper is related to a long list of studies in macroeconomics and growth that examine the effects of fiscal policy on the macroeconomy. While several authors have examined stochastic fiscal policies in real business cycle models (Dotsey (1990), Ludvigson (1996), Schmitt-Grohe and Uribe (2007), Davig et al. (2010), Leeper et al. (2010)), we focus on long-run growth.

We acknowledge that fiscal policy has multiple dimensions that we abstract from. For example, we exclude from our analysis learning about the government fiscal policy (Pastor and Veronesi (2010), Pastor and Veronesi (2011)), and utility-providing expenditures (Ferrière and Karantounias (2011)).

The remainder of this paper is organized as follows. In section 2 we introduce our model and discuss robust preferences, endogenous growth, and the role of government. In section 3, we briefly detail our calibration approach. Our main results are presented in section 4. Section 5 concludes.

2. Model

In this section we describe in detail the stochastic model of endogenous growth that we use to examine the link between long-run growth, fiscal un-

certainty and concerns for robustness. As in Romer (1990), the only source of sustained productivity growth is related to the accumulation of new patents on innovations that facilitate the production of the final good. In this class of models, the speed of patent accumulation, i.e., the growth rate of the economy, depends on the market value of the additional cash flows generated by such innovations. Given that our representative agent has concerns for robustness, the market value of a patent is sensitive to fear about misspecification. Since households price uncertain payoffs using the worst-case distribution, doubts about both future taxation and patents' cash flows generate a premium for exposure to model uncertainty that affects incentives to innovate and growth in the long run.

For simplicity, we abstract from physical capital accumulation. The production of the final good is assumed to depend only on three elements: (i) an exogenous stochastic and stationary productivity process, (ii) the stock of patents, and (iii) the endogenous amount of labor supplied. In our model, labor income is taxed proportionally by the government to finance an exogenous stochastic expenditure stream.

2.1. Household

Consumption Bundle. In each period, the representative agent consumes a bundle u_t of consumption, C_t, and leisure, $1 - L_t$, defined as follows:

$$u_t = \left[\kappa C_t^{1-\frac{1}{\nu}} + (1-\kappa)[A_t(1-L_t)]^{1-\frac{1}{\nu}} \right]^{\frac{1}{1-\frac{1}{\nu}}}.$$

We let L_t and ν denote labor and degree of complementarity between leisure and consumption, respectively. Leisure is multiplied by A_t, our measure of

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standard of living, to guarantee balanced growth when $\nu \neq 1$.

Aversion to Model Uncertainty. We assume that the representative household has Hansen and Sargent (2007) preferences defined over u_t:

$$U_t = (1 - \beta) \ln u_t + \beta \min_{m_{t+1}} [E_t m_{t+1} U_{t+1} + \theta E_t m_{t+1} \ln m_{t+1}],$$

where m_{t+1} is a probability distortion constrained to integrate to unity, and $\theta > 0$ captures confidence in the approximating model. Our agent is afraid that his approximating model is misspecified and considers alternative models that are nearby in the sense of relative entropy ($E_t m_{t+1} \ln m_{t+1}$). This implies that economic decisions are based on a probability measure, $\widetilde{\pi}_{t+1|t}$, optimally slanted towards the worst states. For $\theta = \infty$, there is full trust of the approximating model and these preferences reduce to expected utility. To be precise and fix notation, let $\pi_{t+1|t}$ denote the conditional probability of state s_{t+1} at time t induced by the approximating model. As in Hansen and Sargent (2007), the distorted probability can be linked to $\pi_{t+1|t}$ as follows:

$$\widetilde{\pi}_{t+1|t} = \pi_{t+1|t} \cdot m_{t+1},$$

where the optimal m_{t+1} is

$$m_{t+1} = \frac{e^{-\frac{U_{t+1}}{\theta}}}{E\left[e^{-\frac{U_{t+1}}{\theta}}\right]}.$$

Inserting the optimal distortion m_{t+1} into the preferences of the household delivers the indirect utility function

$$U_t = (1 - \beta) \log u_t - \beta\theta \log E_t \left[e^{-\frac{U_{t+1}}{\theta}} \right]. \tag{1}$$

Robustness concerns, θ, is linked to uncertainty sensitivity, $\gamma_U \geq 1$, by imposing $\theta = -\frac{1}{1-\gamma_U}$. When $\gamma_U = 1$, these preferences collapse to standard time-additive log preferences with risk aversion of one.

The parameter θ determines the detection error probabilities, a likelihood-based measure of models' 'proximity'. Let model A be the approximating model and model B the distorted model. Consider N different samples each with T observations. Let $L_{i,j|k}$ be the likelihood of sample $j \in \{1, 2, ..., N\}$ for model $i \in \{A, B\}$ when model $k \in \{A, B\}$ generates the data. We compute error detection probabilities by assigning prior probabilities over model A and B of 0.5:

$$p(\theta^{-1}) = \frac{1}{2} \frac{1}{N} \sum_{j=1}^{N} \mathcal{I}\left(\frac{L_{A,j|A}}{L_{B,j|A}} < 1\right) + \mathcal{I}\left(\frac{L_{A,j|B}}{L_{B,j|B}} > 1\right), \tag{2}$$

where $\mathcal{I}$ is an indicator function. When models A and B are identical, $p(\theta^{-1})$ is 50%. As the two models begin to diverge from each other, $p(\theta^{-1})$ tends toward zero. In our computations, we set $T = 235$ and $N = 100,000$.

Aversion to Risk. To better highlight the role of robustness, we also study the welfare implications of countercyclical deficit policies in the alternative

case in which the agent has standard time-additive preferences:

$$U_t = \left[(1 - \beta) u_t^{1-\gamma_R} + \beta E_t [U_{t+1}^{1-\gamma_R}] \right]^{\frac{1}{1-\gamma_R}} . \qquad (3)$$

In this setting, the agent does not care about entropy, and the parameter $\gamma_R > 1$ measures only aversion to consumption risk. In section 4.2, we impose $\gamma_U = \gamma_R > 1$ and show that fiscal policies that improve welfare in economies with high risk aversion and no robustness concern (equation (3)) produce welfare costs in economies with high robustness concerns (equation (1)).

Budget Constraint and Optimality. In each period, the household chooses labor, L_t, consumption, C_t, equity shares, Z_t, and public debt holdings, B_t, to maximize utility subject to the following budget constraint:

$$C_t + Q_t Z_t + B_t = (1 - \tau_t) W_t L_t + (Q_t + \mathcal{D}_t) Z_{t-1} + (1 + r_{f,t-1}) B_{t-1}, \qquad (4)$$

where $\mathcal{D}_t$ denotes aggregate dividends (specified in equation (16)) and Q_t is the market value of an equity share. Wages, W_t, are taxed at a time-varying rate, τ_t. The intratemporal optimality condition on labor takes the following form:

$$\frac{1 - \kappa}{\kappa} A_t^{(1-1/\nu)} \left(\frac{C_t}{1 - L_t} \right)^{1/\nu} = (1 - \tau_t) W_t \qquad (5)$$

and implies that the household's labor supply is directly affected by fiscal policy.

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In equilibrium, the following asset pricing conditions hold:

$$Q_t = \mathbb{E}_t[\Lambda_{t+1}(Q_{t+1} + \mathcal{D}_{t+1})],$$

$$1 = \mathbb{E}_t[\Lambda_{t+1}(1 + r_{f,t})],$$

where Λ_{t+1} is the stochastic discount factor of the economy. The representative agent holds the entire supply of equities (normalized to be one for simplicity, i.e., $Z_t = 1 \quad \forall t$) and bonds.

Stochastic Discount Factor. With robustness, the stochastic discount factor Λ_{t+1} is given by

$$\Lambda_{t+1} = \beta \left(\frac{u_{t+1}}{u_t} \right)^{\frac{1}{\nu}-1} \left(\frac{C_{t+1}}{C_t} \right)^{-1/\nu} \frac{\exp(-U_{t+1}/\theta)}{E_t[\exp(-U_{t+1}/\theta)]}, \tag{6}$$

and it can be decomposed as follows:

$$\Lambda_{t+1} \equiv \Lambda_{t+1}^R \Lambda_{t+1}^U,$$

with

$$\Lambda_{t+1}^R \equiv \beta \left(\frac{u_{t+1}}{u_t} \right)^{\frac{1}{\nu}-1} \left(\frac{C_{t+1}}{C_t} \right)^{-1/\nu}$$

and

$$\Lambda_{t+1}^U \equiv \frac{\exp(-U_{t+1}/\theta)}{E_t[\exp(-U_{t+1}/\theta)]}.$$

The first component, Λ_{t+1}^R, is the familiar stochastic discount factor obtained under expected utility with RRA= IES= 1. On the other hand, Λ_{t+1}^U is the minimizing martingale increment associated with the robust agent's problem. When θ approaches infinity ($\gamma_U \to 1$), that component goes to unity, and we

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recover the stochastic discount factor obtained under expected log utility.

We denote expectations under the true and distorted probability measures as $E[\cdot]$ and $\widetilde{E}[\cdot]$, respectively, so that we can rewrite the standard asset pricing equation for any return R_{t+1} as

$$1 = \mathbb{E}_t[\Lambda_{t+1} R_{t+1}] = \tilde{\mathbb{E}}_t[\Lambda_{t+1}^R R_{t+1}],$$

implying that assets are priced by Λ_{t+1}^R under the worst-case distribution.

In this economy, the maximum conditional Sharpe ratio is $\frac{\sigma_t(\Lambda_{t+1})}{E_t(\Lambda_{t+1})}$, which we decompose and interpret in robustness terms. Specifically, in what follows we refer to $\frac{\sigma_t(\Lambda_{t+1}^R)}{E_t(\Lambda_{t+1}^R)}$ as the market price of risk, while $\frac{\sigma_t(\Lambda_{t+1}^U)}{E_t(\Lambda_{t+1}^U)}$ denotes the market price of model uncertainty. We find this terminology more appropriate, as $\sigma_t(\Lambda_{t+1}^U)$ goes to zero when the concerns for robustness disappear even though well-defined risks remain. Because in our economy tax-rate risk is bound up with both productivity and expenditure risk, in what follows we often refer to the market price of model uncertainty as market price of fiscal uncertainty.

Finally, note that when the agent has time-additive preferences as in equation (3), the stochastic discount factor is

$$\Lambda_{t+1} = \beta \left(\frac{u_{t+1}}{u_t} \right)^{\frac{1}{\nu} - \gamma_R} \left(\frac{C_{t+1}}{C_t} \right)^{-1/\nu},$$

and it does not incorporate any robustness concern.

2.2. Technology, Markets, and Government

Final Good Firm. There is a representative and competitive firm that produces the single final output good in the economy, Y_t, using labor, L_t, and a bundle of intermediate goods, X_{it}. We assume that the production function for the final good is specified as follows:

$$Y_t = \Omega_t L_t^{1-\alpha} \left[\int_0^{A_t} X_{it}^\alpha \, di \right] \tag{7}$$

where Ω_t denotes an exogenous stationary stochastic productivity process

$$\log(\Omega_t) = \rho \cdot \log(\Omega_{t-1}) + \epsilon_t, \quad \epsilon_t \sim N(0, \sigma^2),$$

and A_t is the total measure of intermediate goods in use at date t.

This competitive firm takes prices as given and chooses intermediate goods and labor to maximize profits as follows:

$$D_t = \max_{L_t, X_{it}} Y_t - W_t L_t - \int_0^{A_t} P_{it} X_{it} di,$$

where P_{it} is the price of intermediate good i at time t. At the optimum,

$$X_{it} = L_t \left(\frac{\Omega_t \alpha}{P_{it}} \right)^{\frac{1}{1-\alpha}}, \quad \text{and} \quad W_t = (1-\alpha) \frac{Y_t}{L_t}. \tag{8}$$

Intermediate Goods Firms. Each intermediate good $i \in [0, A_t]$ is produced by an infinitesimally small monopolistic firm. Each firm needs X_{it} units of the final good to produce X_{it} units of its respective intermediate good i. Given this assumption, the marginal cost of an intermediate good is fixed

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and equal to one. Taking the demand schedule of the final good producer as given, each firm chooses its price, P_{it}, to maximize profits, Π_{it}:

$$\Pi_{it} \equiv \max_{P_{it}} P_{it}X_{it} - X_{it}.$$

At the optimum, monopolists charge a constant markup over marginal cost:

$$P_{it} \equiv P = \frac{1}{\alpha} > 1.$$

Given the symmetry of the problem for all the monopolistic firms, we obtain

$$
\begin{aligned}
X_{it} &= X_t = L_t(\Omega_t\alpha^2)^{\frac{1}{1-\alpha}}, &(9)\\
\Pi_{it} &= \Pi_t = (\frac{1}{\alpha} - 1)X_t.
\end{aligned}
$$

Equations (7) and (9) allow us to express final output in the following compact form:

$$Y_t = \frac{1}{\alpha^2}A_tX_t = \frac{1}{\alpha^2}A_tL_t(\Omega_t\alpha^2)^{\frac{1}{1-\alpha}}. \qquad (10)$$

Since both labor and productivity are stationary, the long-run growth rate of output is determined by the expansion of the intermediate goods variety, A_t. This expansion originates in the research and development sector that we describe below.

Research and Development. Innovators develop new intermediate goods for the production of final output and obtain patents on them. At the end of the period, these patents are sold to new intermediate goods firms in a competitive market. Starting from the next period on, the new monopolists

produce the new varieties and make profits. We assume that each existing variety dies, i.e., becomes obsolete, with probability $\delta \in (0,1)$. In this case, its production is terminated. Given these assumptions, the cum-dividend value of an existing variety, V_{it}, is equal to the present value of all future expected profits and can be recursively expressed as follows:

$$V_{it} = V_t = \Pi_t + (1-\delta)E_t\left[\Lambda_{t+1}V_{t+1}\right] \tag{11}$$

Let $1/\vartheta_t$ be the marginal rate of transformation of final goods into new varieties. The free-entry condition in the R&D sector implies that in equilibrium,

$$\frac{1}{\vartheta_t} = E_t\left[\Lambda_{t+1}V_{t+1}\right]. \tag{12}$$

The left-hand side of the free-entry condition measures the marginal cost of producing an extra variety. The right-hand side, in contrast, is equal to the end-of-period market value of the new patents. Equation (12) is at the core of this class of models because it implicitly pins down the optimal level of investment in R&D and ultimately the growth rate of the economy. To see this more clearly, let S_t denote the units of final good devoted to R&D investment, and notice that in our economy the total mass of varieties evolves according to

$$A_{t+1} = \vartheta_t S_t + (1-\delta)A_t, {}^1 \tag{13}$$

---

^{1}This dynamic equation is consistent with our assumption that new patents survive for sure in their first period of life. If new patents are allowed to immediately become obsolete, equations (12) and (13) need to be replaced by $A_{t+1} = (1-\delta)(\vartheta_t S_t + A_t)$ and $\frac{1}{\vartheta_t} = E_t\left[\Lambda_{t+1}(1-\delta)V_{t+1}\right]$, respectively. Our results are not sensitive to this modeling choice.

from which we obtain

$$\frac{A_{t+1}}{A_t} - 1 = \vartheta_t \frac{S_t}{A_t} - \delta.$$

Following Comin and Gertler (2006), we impose

$$\vartheta_t = \chi \left(\frac{S_t}{A_t} \right)^{\eta - 1} \qquad \eta \in (0, 1), \tag{14}$$

in order to capture the idea that concepts already discovered make it easier to come up with new ideas, $\partial \vartheta / \partial A > 0$, and that R&D investment has decreasing marginal returns, $\partial \vartheta / \partial S < 0$.

Combining equations (12)–(14), we obtain the following optimality condition for investment:

$$\frac{1}{\chi} \left(\frac{S_t}{A_t} \right)^{1-\eta} = E_t \left[\sum_{j=1}^{\infty} \Lambda_{t+j|t} (1-\delta)^{j-1} \left(\frac{1}{\alpha} - 1 \right) (\Omega_{t+j} \alpha^2)^{\frac{1}{1-\alpha}} L_{t+j} \right] \tag{15}$$

where $\Lambda_{t+j|t} \equiv \prod_s^j \Lambda_{t+s|t}$ is the j–steps-ahead pricing kernel. Equation (15) suggests that the extent of innovation intensity in the economy, S_t/A_t, is directly related to the discounted value of future profits and, ultimately, future labor conditions. When agents expect labor above steady state, they will have an incentive to invest more in R&D, ultimately boosting long-run growth. Vice versa, when agents expect labor to remain below steady state, they will revise downward their evaluation of patents and will reduce their investment in innovation and, therefore, future growth. We discuss this intuition further in section 2.3.

Stock Market. Given the multisector structure of the model, various assumptions on the constituents about the stock market can be adopted. We assume

that the stock market value includes all the production sectors described above, namely, the final good, the intermediate goods, and the R&D sector. Taking into account the fact that both the final good and the R&D sector are competitive, aggregate dividends are simply equal to monopolistic profits net of investment:

$$\mathcal{D}_t = \Pi_t A_t - S_t. \tag{16}$$

Government. The government faces an exogenous and stochastic expenditure stream, G_t, that evolves as follows:

$$\frac{G_t}{Y_t} = \frac{1}{1 + e^{-gy_t}}, \tag{17}$$

where

$$gy_t = (1 - \rho)\overline{gy} + \rho_g gy_{t-1} + \epsilon_{G,t}, \quad \epsilon_{G,t} \sim N(0, \sigma_{gy}^2).$$

This specification ensures that $G_t \in (0, Y_t) \quad \forall t$. In order to finance these expenditures, the government can use tax income, $T_t = \tau_t W_t L_t$, or public debt according to the following budget constraint:

$$B_t = (1 + r_{f,t-1})B_{t-1} + G_t - T_t. \tag{18}$$

We focus on two tax regimes. Under the first, the government commits to a zero-deficit policy and sets the tax rate, τ_t^{zd}, as follows:

$$\tau_t^{zd} = \frac{G_t/Y_t}{1 - \alpha}.$$

In this case, the tax rate perfectly mimics the properties of our exogenous government expenditure process. Under the second regime, in contrast, the government runs surpluses or deficits according to the following rule for the debt-output ratio:

$$\frac{B_t}{Y_t} = \rho_B \frac{B_{t-1}}{Y_{t-1}} + \phi_B \cdot (\log L_{SS} - \log L_t), \qquad (19)$$

where L_{SS} is the steady-state level of labor, $\rho_B \in (0,1)$ measures the inverse of the speed of debt repayment, and $\phi_B \geq 0$ is the intensity of the policy. Combining (18) and (19), the tax rate becomes

$$\tau_t(\rho_B, \phi_B) = \tau_t^{zd} + \frac{1}{1-\alpha}\left(\frac{1+r_{f,t-1}}{Y_t/Y_{t-1}} - \rho_B\right)\frac{B_{t-1}}{Y_{t-1}} + \phi_B\frac{\log L_t - \log L_{SS}}{1-\alpha}. \qquad (20)$$

When $\phi_B > 0$, our simple debt policy rule captures the behavior of a government that is concerned about employment and wants to minimize labor fluctuations. In particular, the government cuts labor taxes (increases debt) when labor is below steady state and increases them (reduces debt) in periods of boom for the labor market. The second term on the right-hand side of equation (20) captures the persistent effect that debt repayment has on taxes. The condition $\rho_B < 1$ ensures that the public administration keeps the debt-output ratio stationary. In the language of Leeper et al. (2010), we anchor expectations about debt and rule out unsustainable paths.

Aggregate Resource Constraint. In this economy, the final good market clearing condition implies:

$$Y_t = C_t + S_t + A_t X_t + G_t.$$

Final output, therefore, is used for consumption, R&D investment, production of intermediate goods, and public expenditure.

2.3. Some Properties of the Equilibrium

Combining equations (12)—(15), it is possible to show that as long as $\eta \in (0, 1)$ the growth rate of the economy is a positive monotonic transformation of the patent value:[2]

$$\frac{A_{t+1}}{A_t} = 1 - \delta + \chi^{\frac{1}{1-\eta}} E_t \left[\Lambda_{t+1} V_{t+1} \right]^{\frac{\eta}{1-\eta}}. \tag{21}$$

This implies that characterizing the impact of both robustness and tax uncertainty on long-run growth is isomorphic to analyzing the asset pricing properties of both patent value and pricing kernel. To this aim, assume for the time being that log profits, $\ln \Pi_t$, and log consumption bundle growth, Δc_t, are jointly linear-gaussian and contain a predictable component:

$$
\begin{aligned}
\Delta c_{t+1} &= \mu + x_{c,t} + \sigma_c^{SR} \varepsilon_{t+1}^c &\tag{22}\\
\ln \Pi_{t+1} &= \overline{\Pi} + x_{\Pi,t} + \sigma_\Pi^{SR} \varepsilon_{t+1}^\pi \\
x_{c,t+1} &= \rho_c x_{c,t} + \sigma_c^{LR} \varepsilon_{t+1}^{xc} \\
x_{\Pi,t+1} &= \rho_\Pi x_{\Pi,t} + \sigma_\Pi^{LR} \varepsilon_{t+1}^{x\Pi} \\
\varepsilon_{t+1} &\equiv \left[\begin{array}{cccc} \varepsilon_{t+1}^c & \varepsilon_{t+1}^\pi & \varepsilon_{t+1}^{xc} & \varepsilon_{t+1}^{x\Pi} \end{array} \right] \sim i.i.d.N.(\overrightarrow{0}, \Sigma),
\end{aligned}
$$

where Σ has ones on its main diagonal. In the spirit of Bansal and Yaron (2004), we think of ε^c and ε^π as short-run shocks to consumption growth and

---

[2]If $\eta = 1$, the supply of new patents is perfectly flexible and their value has to be constant over time: $\vartheta_t = \chi$.

profits, respectively. The predictable components x_Π and x_c, in contrast, are long-run risks.

To stay as close as possible to the Bansal and Yaron (2004) framework, assume also that $C_t/(A_t(1 - L_t))$ is constant. Given these simplifying assumptions, we obtain the following exact closed-form solution for the pricing kernel:

$$\ln \Lambda_{t+1} - E_t[\ln \Lambda_{t+1}] = \begin{cases} -\gamma_R \sigma_c^{SR} \varepsilon_{t+1}^c & \text{CRRA} \\ -\gamma_U \sigma_c^{SR} \varepsilon_{t+1}^c - \beta \frac{\gamma_U - 1}{1 - \rho_c \beta} \sigma_c^{LR} \varepsilon_{t+1}^{xc} & \text{Robustness.} \end{cases} \quad (23)$$

By no arbitrage, the log return of a patent, $r_{V,t+1} = \ln(V_{t+1}/(V_t - \Pi_t))$, satisfies the following condition:

$$r_{V,t+1} - E_t[r_{V,t+1}] \approx \kappa_2 \sigma_\Pi^{SR} \epsilon_{t+1}^\Pi - \frac{\kappa_1}{1 - \kappa_1 \rho_c} \sigma_c^{LR} \epsilon_{t+1}^{xc} + \frac{\kappa_2}{1 - \kappa_1 \rho_\Pi} \sigma_\Pi^{LR} \epsilon_{t+1}^{x\Pi}, \quad (24)$$

where $\kappa_1 = (\overline{V} - \overline{\Pi})/\overline{V}$ and $\kappa_2 = \overline{\Pi}/\overline{V}$ are approximation constants.

Since the average value of a patent is decreasing in the risk premium of its return, $E_t[r_{V,t+1} - r_t^f] \approx -cov_t(\ln \Lambda_{t+1}, r_{V,t+1})$, these equations help us to make three relevant points. First, with CRRA preferences, the reduction of short-run consumption risk, σ_c^{SR}, is sufficient to reduce the market price of risk and hence the riskiness of the patents, i.e., short-run stabilization promotes growth.

Second, with robustness preferences, the market price of risk strongly depends on both the persistence, ρ_c, and the volatility, σ_c^{LR}, of the long-run component in consumption. For high enough values of γ_U, growth is pinned down mainly by long-run consumption risk, as opposed to short-run risk.

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Third, in general equilibrium our cash-flow parameters are endogenous objects and depend on fiscal policy through ϕ_B and ρ_B. After calibrating the model, we explore the role of ϕ_B and ρ_B in varying the amount of short- and long-run risk and altering long-run growth.

3. Calibration

We report our benchmark calibration in table 1 and the implied main statistics of the model in table 2. Our parameter choices are based on the zero-deficit policy, and we exploit balanced growth restrictions whenever applicable. Our productivity process is then calibrated to replicate several key properties of US consumption growth over the long sample 1929–2008. We choose a long sample to better capture long-run growth dynamics. Under our benchmark calibration, average annual consumption growth is 2.8%, while the volatility is about 2.6%.

The parameters for the government expenditure-output ratio are set to have an average share of 10% at the deterministic steady state and an annual volatility of 4%, consistent with US annual data over the sample 1929–2008. Under the zero-deficit policy, this parameterization implies an average labor tax rate of 33.5%, in line with the empirical counterpart in our sample.

The robustness parameter θ and subjective discount factor β are set to replicate the low historical average of the risk-free rate and the consumption claim risk premium estimated by Lustig et al. (2010). The replication of these asset-pricing moments is important because it imposes a strict discipline on the way in which innovations are priced and average growth is determined. Our choice of θ corresponds to setting $\gamma_U = 10$, which implies

a detection error probability of 1.15%. The parameters ν and κ control the labor supply and are chosen to yield steady-state hours worked of 1/3 of the time endowment and a steady-state Frisch elasticity of 0.7, respectively, in line with the empirical evidence.

Turning to technology parameters, the constant α captures the relative weight of labor and intermediate goods in the production of final goods, and, by equation (9), controls the markup and hence profits in the economy. We choose this parameter to match the empirical share of profits in aggregate income of about 16%. The parameter η, the elasticity of new intermediate goods with respect to R&D, is within the range of panel and cross-sectional estimates of Griliches (1990). Since the variety of intermediate goods can be interpreted as the stock of R&D (a directly observable quantity), we can then interpret δ as the depreciation rate of the R&D stock. We set $1 - \delta$ to 0.97, which corresponds to an annual depreciation rate of about 14%, i.e., the value assumed by the Bureau of Labor Statistics in its R&D stock calculations. The scale parameter χ is chosen to match the average growth rate.

4. The Market Price of Fiscal Uncertainty

In this section we study the link between concerns for robustness, fiscal uncertainty, and growth. We first assume that the government is committed to a zero-deficit policy. This case serves as a useful benchmark highlighting the basic features of our model. Second, we examine the effectiveness of common countercyclical and persistent deficit policies.

Description	Symbol	Value
Preference Parameters		
Consumption-Labor Elasticity	ν	0.72
Utility Share of Consumption	κ	0.11
Discount Factor	β	0.997
Robustness Concern	θ	0.111
Technology Parameters		
Elasticity of Substitution Between Intermediate Goods	α	0.7
Autocorrelation of Productivity	ρ	0.97
Scale Parameter	χ	0.52
Survival rate of intermediate goods	$1 - \delta$	0.97
Elasticity of New Intermediate Goods wrt R&D	η	0.83
Standard Deviation of Technology Shock	σ	0.006
Government Expenditure Parameters		
Level of Expenditure-Output Ratio (G/Y)	$\overline{gy}$	-2.2
Autocorrelation of G/Y	ρ_G	0.98
Standard deviation of G/Y shocks	σ_G	0.008

Notes - This table reports the benchmark quarterly calibration of our model discussed in section 3.

4.1. Zero-Deficit Policies

Under the zero-deficit policy, exogenous shocks to the expenditure-output ratio are fully absorbed in the tax rate in each period and each state of the world. The properties of the tax rate process are determined solely by the properties of both the exogenous productivity and public expenditure shocks.

In table 2 we report various moments from simulations of our model computed both true and distorted measures. We focus on varying degrees of robustness concerns as captured by detection error probabilities. Column 2 refers to our benchmark calibration; the other columns are obtained by progressively reducing γ_U while keeping the other parameters fixed.

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	Data	Benchmark	$p(\theta^{-1}) = 5\%$	$p(\theta^{-1}) = 10\%$
		Table 2: Main Statistics under Zero-Deficit		
$\sigma(\Delta c)$	2.60	2.67	2.68	2.69
$ACF_1(\Delta c)$	0.44	0.45	0.44	0.43
$\sigma(E_t[\Delta c_{t+1}])$		0.49	0.47	0.46
$ACF_1(E_t[\Delta c_{t+1}])$		0.93	0.93	0.93
$E(\Delta c) - \tilde{E}(\Delta c)$		1.35	0.87	0.57
$\tilde{E}(\epsilon)$		$-1.56e^{-3}$	$-9.98e^{-4}$	$-6.55e^{-4}$
$\tilde{E}(\epsilon_G)$		$2.01e^{-4}$	$1.24e^{-4}$	$0.77e^{-4}$
$\tilde{E}(\tau) - E(\tau)$		0.05	0.02	0.01
$\tilde{E}(\log(V)) - E(\log(V))$		-0.57	-0.39	-0.26
$E(\log \frac{U}{A})$		99.56	99.88	100.08
$E(r^{C,ex})$		1.76	1.15	0.77
$E(\tau)$	33.5	33.51	33.51	33.51
$\sigma(\tau)$		2.64	2.63	2.63

Notes - This table reports the annualized summary statistics obtained from simulations of our model. The benchmark case corresponds to the calibration in table 1. For the other cases, we adjust θ to obtain the indicated detection error probabilities, $p(\theta^{-1})$. All figures are multiplied by 100, except the first-order autocorrelation, ACF_1, and the distorted expectations $\tilde{E}(\epsilon)$ and $\tilde{E}(\epsilon_G)$. The excess returns to the consumption claim are denoted by $r^{C,ex}$. Tax rate, value of patents, and standardized utility in log units are denoted by τ, V, and $\log \frac{U}{A}$, respectively.

Consider first the implied moments for consumption growth, i.e., the main determinant of welfare. The unconditional volatility of consumption is close to its empirical counterpart across all levels of error detection probabilities. After taking time aggregation into account, the autocorrelation of annualized consumption growth is modest. On the other hand, the conditional expectation of consumption growth is volatile and extremely persistent, implying that the model generates a fair amount of endogenous long-run consumption risk.

Given the strong impact that long-run risk has on discounted entropy, the

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gap between the true and distorted expected growth rates of consumption is sizeable. Furthermore, since our model is very close to log-linear, we observe distortions only in the first moment of our variables of interest, consistent with the results of Anderson et al. (2003) and Bidder and Smith (2011), who document no distortion in second or higher moments.

The negative distortion in expected consumption growth is the natural result of pessimistic expectations about both productivity and government expenditure shocks. Our agent, indeed, slants probabilities toward states in which productivity shocks are negative and government expenditure shocks are positive. In these states, the tax base is low while the liabilities of the government are high. Agents, therefore, expect higher levels of taxation under the undesired worst-case scenario. Equation (21) clarifies the implications of these distortions for growth: a higher expected tax rate triggers a permanent decrease in after-tax expected wages, labor supply, future profits, and perceived value of patents, $\tilde{E}(\log(V))$, ultimately discouraging investment in innovative products.

As robustness concerns increase, the implied decline in the value of patents and growth depresses welfare to a greater extent. Simultaneously, the desire for further robustness increases model uncertainty and hence the premium associated with consumption cash flow. Our benchmark specification generates a substantial consumption risk premium of about 1.75, in line with the empirical estimates of Lustig et al. (2010). This premium is mainly driven by model uncertainty, as shown by the fact that it rapidly decreases when the concern for robustness declines.

Under our benchmark calibration, the average tax rate is roughly 33.5%,

consistent with the data. On the other hand, the implied volatility of taxes is moderate, in the order of 2.6%. Our results, therefore, are not driven by an excessively volatile tax rate.

These results can be better understood by examining the impulse responses of key quantities after a positive one-standard-deviation shock to G/Y. In figure 2 we depict the dynamic response of both short- and long-horizon variables for various degrees of robustness concerns. We distinguish between aversion to model uncertainty and aversion to risk (the dash-dotted green line). We start by discussing the case of aversion to model uncertainty.

When an adverse government shock materializes, labor tends to fall, as figure 2 shows. This is due to a substitution effect: under the zero-deficit policy, higher government expenditures directly translate into a higher tax, which depresses the supply of labor. This effect gets weaker when the concern for robustness becomes stronger. This reflects the intuition that a greater concern for robustness makes the agent feel more pessimistic and work harder (income effect). However, the more stable short-run dynamics come at the cost of lower expected recovery speed (top-right panel). This is because agents perceive higher expected taxes when the robustness concerns are more severe.

Output and consumption exhibit similar patterns when we focus on their short-run dynamics (left panels): stronger concerns for robustness are associated with more stable short-run responses. Expected output and consumption growth (right panels)drop when aversion to model uncertainty increases. According to equations (21)–(24), this result can be explained by examining the two key determinants of aggregate growth, namely expected future prof-
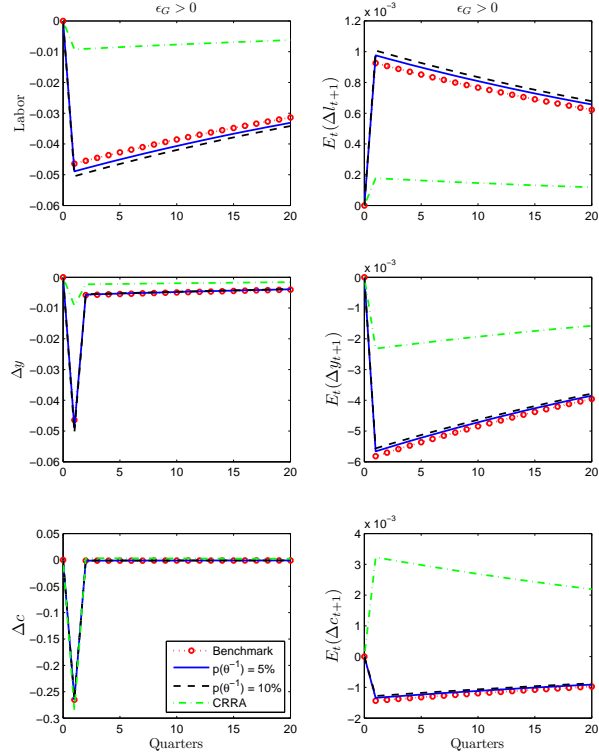
Figure 2: Short- and Long-Run Dynamics following adverse G/Y Shock

Notes - This figure shows quarterly log-deviations from the steady state multiplied by 100. The benchmark case corresponds to the calibration in table 1. For the other cases, we adjust θ to obtain the indicated detection error probabilities. CRRA corresponds to time-additive preferences described in (3) with $\gamma_R = 10$.

its and the stochastic discount factor. Since government expenditures are persistent, the agent anticipates higher expenditures and hence higher tax rates for the long-run. The lower incentives to supply labor generate lower long-run expected profits and hence a severe drop in the value of patents. Since investments fall, expected growth is automatically revised downward. On the discount rate side, an increase in aversion to model uncertainty amplifies the expectations adjustment just described. The cash-flow and discount

	Benchmark	$p(\theta^{-1}) = 5\%$	$p(\theta^{-1}) = 10\%$	CRRA
$\sigma(\Lambda)/E(\Lambda)$	0.28	0.18	0.13	0.09
$\sigma(\Lambda^U)/E(\Lambda^U)$	0.26	0.17	0.11	0.00

Notes - This table reports market price of risk and fiscal uncertainty under different degrees of robustness concerns. The benchmark case corresponds to the calibration in table 1. For the other cases, we adjust θ to obtain the indicated detection error probabilities, $p(\theta^{-1})$. The last column refers to the case in which the agent has time-additive CRRA preferences as in equation (3) with relative risk aversion equal to 10.

rate channels, therefore, work in the same direction and reinforce each other.

In our benchmark calibration, the implicit value for γ_U is 10. The dashed and dotted lines in figure 2 refer to the case in which we impose $\gamma_R = 10$ and focus on risk aversion with CRRA preferences, as in equation (3). The dynamics of consumption changes drastically when we focus on an economy featuring pure aversion to risk. First of all, upon the realization of an adverse government expenditure shock, labor falls much less, the reason being that in this setting the agent cares only about short-run uncertainty, and investment decisions are no longer significantly sensitive to a long-run increase in taxes. Expected long-run growth of output, therefore, falls by less. Long-run consumption growth actually becomes positive, as the agent anticipates that government expenditures will decline as a fraction of output and will leave more resources available for private consumption.

The dynamics of macroeconomic quantities depend crucially on whether we capture aversion to model uncertainty or risk (figure 2). To be more precise about this point, in table 3 we show volatility and composition of the pricing kernel Λ for all four calibrations used in figure 2.

Our benchmark model generates a maximum Sharpe ratio of 0.28, well within the Hansen and Jagannathan (1991) bound. Across all the calibrations of θ, almost all of the volatility of the pricing kernel can be attributed to model uncertainty. Intuitively, our model generates persistent variations in expected consumption growth that are a source of serious concern for an agent seeking robustness, since such low-frequency dynamics are hard to detect in a short sample. These persistent variations in expected consumption growth are a source of long-run risk (Bansal and Yaron (2004)) endogenously related to investment and public expenditure shocks.

With standard time-additive CRRA preferences, the agent is not concerned with long-run model uncertainty, and for this reason all the pricing kernel volatility is related to short-run consumption volatility. Even when the relative risk aversion, γ_R, is calibrated to a value as high as 10, the market price of risk remains small, as the agent manages to hedge a substantial amount of short-run consumption risk through investments.

Summarizing, we find that fiscal uncertainty in an endogenous growth setting with robustness concerns leads to higher perceived taxation, lower perceived growth, and welfare losses. These welfare losses are intimately connected to the volatility of the stochastic discount factor, which is driven almost exclusively by model uncertainty. These findings suggest that even a small alteration of tax dynamics can produce substantial changes in growth and welfare. In the next section we connect model uncertainty to more general public financing policies aimed at stabilizing the economy over the short run and show that they may actually be suboptimal with respect to a simple zero-deficit policy.

4.2. Public Debt and Endogenous Tax Uncertainty

In this section we allow the government to run deficits and surpluses and let taxes evolve according to equation (20). In panels A and B of figure 3 we depict the response of the tax rate after a positive shock to government expenditures and a negative shock to productivity, respectively. According to equation (19), in both cases the government responds to these shocks by initially lowering the tax rate below the level required to have a zero deficit. Over the long horizon, however, the government increases taxation above average in order to run surpluses and repay debt. Good news for short-run taxation levels always comes with bad news for long-run fiscal pressure. Since this is true also with time-additive preferences, for the sake of brevity we plot only the responses under our benchmark calibration.

The main goal of the remainder of this section is to illustrate that with robustness preferences the welfare implications of commonly used counter-cyclical deficit rules are quite different from those normally obtained with time-additive preferences. In what follows, we first describe the impact of this fiscal policy on macroeconomic aggregates by looking at impulse response functions. Second, we show that our simple countercyclical fiscal policy generates welfare benefits with respect to a simple zero-deficit rule when the agent has CRRA preferences. Third, we show that when the agent is averse to model uncertainty, the same fiscal policy may generate, in contrast, significant welfare costs.

a) positive expenditure shock   b) negative productivity shock
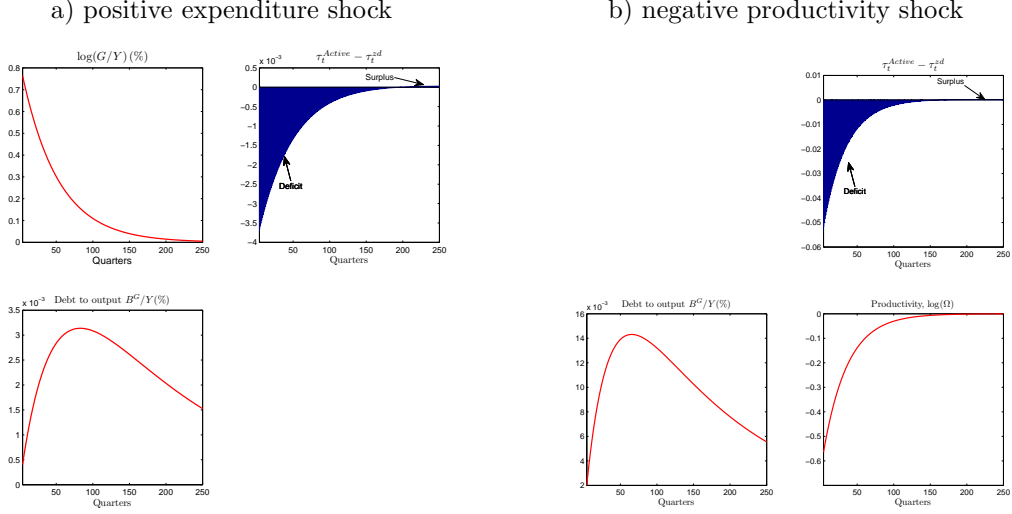

Figure 3: Impulse response of Tax Rate and Debt

Notes - This figure shows quarterly log-deviations from the steady state for the government expenditure-output ratio (G/Y), debt-output ratio (B/Y), and labor tax (τ). Panel A refers to an adverse shock to government expenditure. Panel B refers to a negative productivity shock. All deviations are multiplied by 100. All the parameters are calibrated to the values used in table 1. The zero-deficit policy is obtained by imposing $\phi_B = 0$. The countercyclical policy is obtained by setting $\rho_B^4 = .975$ and $\phi_B = 0.25\%$.

4.2.1. Short-run dynamics and long-run expectations

Keeping the behavior of the tax rate in mind, we now turn our attention to the behavior of labor, output, and consumption growth upon the realization of an adverse government expenditure shock. The left-hand panels of figure 4 show the short-run dynamics of these macroeconomic quantities, while the right-hand panels depict the response of conditional expectations. We point out two relevant differences. First, the responses of l_t, Δy_t, and Δc_t upon the realization of an adverse expenditure shock are less pronounced than those observed in figure 2 in the zero-deficit specification. This implies that our exogenous policy accomplishes the task for which it is designed, i.e., it
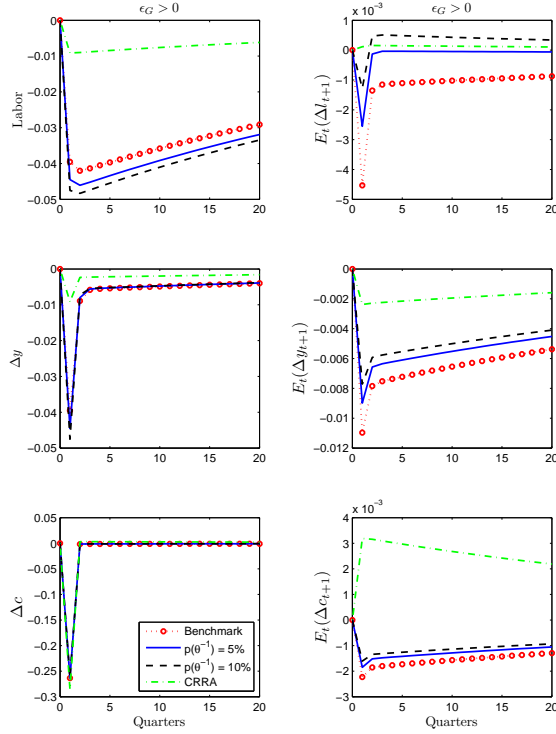
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Figure 4: Impulse Response Functions with Tax Smoothing

Notes - This figure shows impulse response functions under the probability measure induced by the approximating model. All the parameters are calibrated to the values used in table 1. The lines depicted in each plot are associated with different levels of robustness concerns, $\theta = -(1 - \gamma_U)^{-1}$, and detection error probabilities, $p(\theta^{-1})$. Under the benchmark calibration, $\gamma_U = 10$. The dashed and dotted line refer to the time-additive CRRA case with $\gamma_R = 10$.

reduces short-run fluctuations.

Second, under CRRA the response of the conditional expectations is almost unaltered with respect to the zero-deficit case. Under the robustness case, however, the adjustment is *amplified* when deficits are countercyclical. Specifically, in the economy with robustness concerns, the short-run stabilization comes at the cost of having a more pronounced and pessimistic adjustment of the expectations about future growth. According to equa-

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tion (21), expectations about growth are just a monotonic transformation of patents' values, and ultimately depend on the properties of profits.

In figure 5(a) we show what happens to both the intertemporal composition of profit risk and the value of a patent as we change the policy parameters (ρ_B, ϕ_B) under our benchmark calibration. For a given ρ_B, as the intensity of the policy ϕ_B increases, the short-run volatility of profits declines (top-right panel), while simultaneously the long-run component of profits becomes more persistent (bottom-left panel). When the household cares about discounted entropy, more persistent long-run profit fluctuations may generate a substantial increase in the average excess return. In our case, as ϕ_B increases, the government budget constraint triggers more severe long-run taxation adjustments, which produce long-lasting adverse fluctuations in labor and profits. The increased persistence of long-run profits dominates the decline of short-run risk and causes future profits to be discounted at a higher rate. This explains why a more intense countercyclical deficit policy ultimately depresses patent values (top-left panel) and growth.

Furthermore, the negative effects of countercyclical deficit policies on patent valuation and growth become more severe when the debt persistence, ρ_B, increases. More persistent tax-rate fluctuations amplify long-lasting profit risk and depress growth even though more short-run stabilization is achieved. With time-additive CRRA preferences, in contrast, the value of the patents increases with cyclical deficit policies, as shown in figure 5(b), because there is no concern about model uncertainty, and fiscal stabilization indeed reduces aggregate short-run risk.
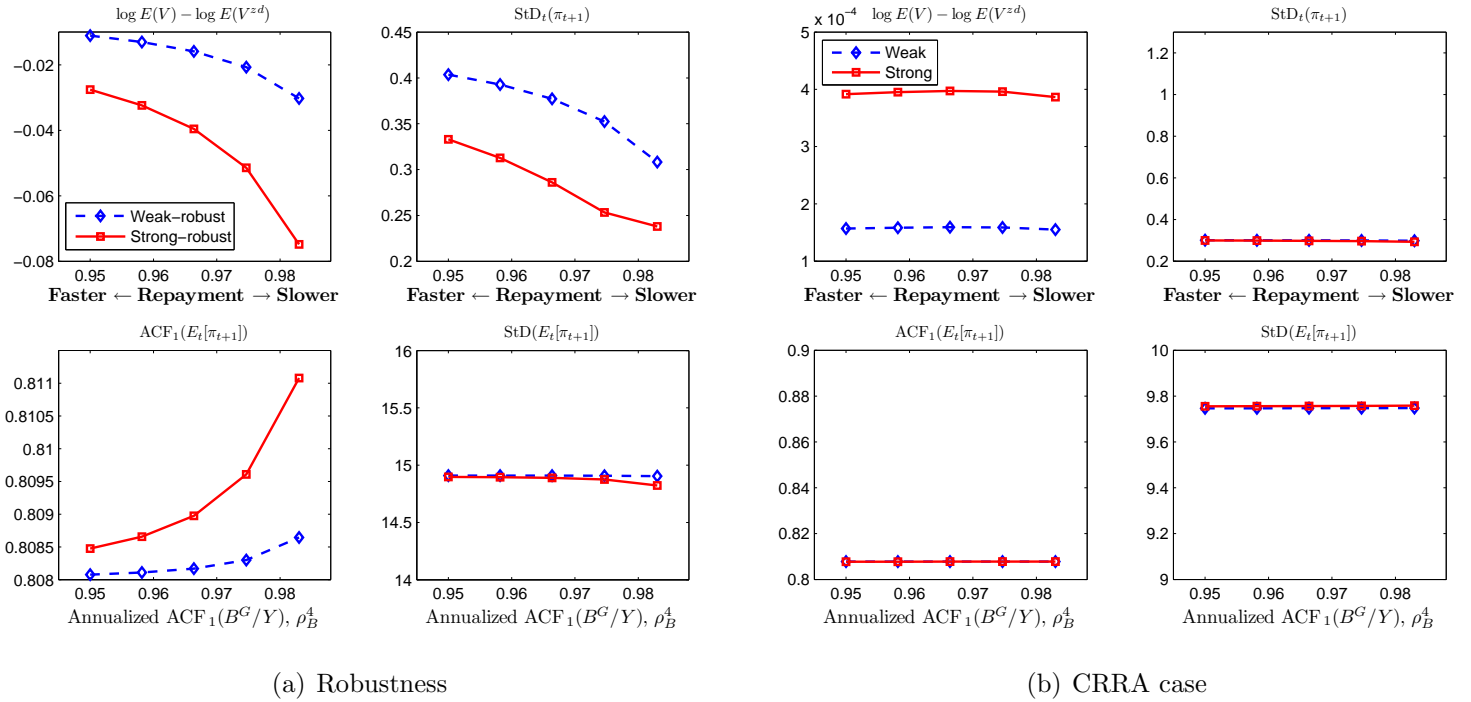
(a) Robustness
(b) CRRA case

Figure 5: Patents' Value and Profits Distribution

Notes - This figure shows the average value of patents, $E[V]$, and key moments of log profits, $\pi = \ln \Pi$. $\mathrm{StD}_t(\pi_{t+1})$, $\mathrm{StD}(E_t[\pi_{t+1}])$ and $\mathrm{ACF}_1 E_t[\pi_{t+1}])$ are the model counterparts of σ_Π^{SR}, ρ_Π, and σ_Π^{LR} in (22), respectively. All the parameters are calibrated to the values used in table 1. In panel A, we use preferences for robustness and fix $\gamma_U = 10$. In panel B, we use CRRA preferences with $\gamma_R = 10$. The two lines reported in each plot are associated to different levels of intensity of the countercyclical fiscal policy described in equation (19). 'Weak' and 'strong' policies are generated by calibrating ϕ_B to 0.1% and 0.25%, respectively. The horizontal axis corresponds to different annualized autocorrelation, ρ_B^4, of the debt-to-output ratio, B^G/Y; the higher the autocorrelations, the lower the speed of repayment.

Taken together, these results suggest that the intertemporal distribution of tax distortions matters when the agent assumes the worst-case scenario. In a model with endogenous growth and robustness concerns, the financing mix of taxes and debt significantly feeds back on patent valuation and long-run growth prospects.

4.2.2. Welfare and growth incentives

We measure welfare costs in terms of percentage of lifetime consumption bundle. Details about the computations are reported in the appendix. We start by focusing on the case of time-additive preferences where γ_R is a pure measure of risk aversion. In the top-left panel of figure 6(b), we plot welfare costs (benefits) obtained by departing from the zero-deficit policy and implementing countercyclical deficits with different levels of intensity, ϕ_B, and persistence, ρ_B. The top- and the bottom-right panels show short- and long-run consumption risk as a function of ϕ_B and ρ_B, respectively. The bottom-left panel shows changes in the unconditional growth rate of consumption with respect to a zero-deficit policy.

The main message of this figure is simple: with standard preferences, our exogenous financing policy is able to reduce short-run consumption risk, promote growth, and generate welfare benefits. These results, however, are completely overturned under our benchmark calibration featuring robustness concerns, as shown in figure 6(a).

The top-left panel of this figure, indeed, shows that standard countercyclical financing policies may produce welfare losses that are very sizable, especially relative to the small benefits depicted in figure 6(b). The top-right panel of figure 6(a) shows that the government is still able to stabilize con-

sumption dynamics in the short run when using more aggressive fiscal policies (stronger intensity, ϕ_B, or persistence, ρ_B). The problem, however, is that such short-run stabilization comes at the cost of increased persistence of long-run profits, which yields more pronounced long-run consumption fluctuations and lower unconditional growth. Since growth is a first-order determinant of welfare, the final result is an impoverishment of the household.

Countercyclical fiscal policies are indeed able to reduce model uncertainty, no matter whether we measure it through detection error probabilities (top-left panel of figure 7), distortions to expected productivity and expenditure shocks (top-right and bottom-left panels, respectively), or market price of fiscal uncertainty (bottom-right panel).

Unfortunately, however, these accomplishments come at the cost of allowing more long-run profit *risk* (higher ρ_Π in the linear cash-flow specification (22)). We emphasize the word risk because the increase in the persistence of the profit fluctuations is obtained under both the true and distorted probability measures. As anticipated, we find no significant distortion in second moments. The agent hence is perfectly aware that a stronger countercyclical deficit policy produces stronger swings in long-run tax rates, labor, profits, and growth.

In a model with exogenous growth, the reduction of model uncertainty automatically produces substantial welfare benefits (Barillas et al. (2009)), but in an endogenous-growth economy, the reduction of model uncertainty can come at the cost of depressing growth for the long-run. More broadly, our welfare results suggest that this trade-off should be taken seriously into account when working on optimal fiscal policy design, and that the current
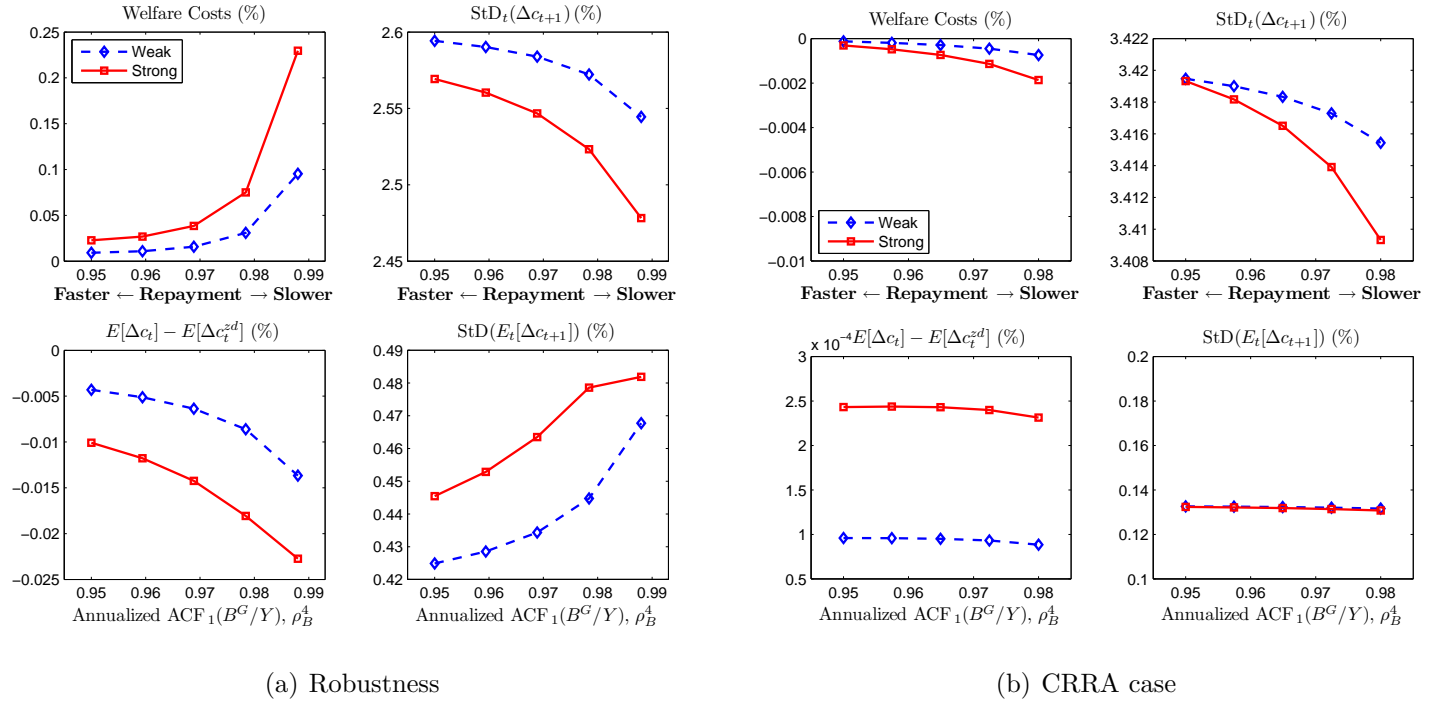
(a) Robustness

(b) CRRA case

Figure 6: Welfare Costs and Consumption Distribution

Notes - This figure shows the welfare costs and key moments of consumption growth. $\text{StD}_t(\Delta c_{t+1})$, $\text{StD}(E_t[\Delta c_{t+1}])$ and $\text{ACF}_1 E_t[\Delta c_{t+1}])$ are the model counterparts of σ_c^{SR}, ρ_c, and σ_c^{LR} in (22), respectively. All the parameters are calibrated to the values used in table 1. In panel A, we use preferences for robustness and fix $\gamma_U = 10$. In panel B, we use CRRA preferences with $\gamma_R = 10$. The two lines reported in each plot are associated with different levels of intensity of the countercyclical fiscal policy described in equation (19). 'Weak' and 'Strong' policies are generated by calibrating ϕ_B to 0.1% and 0.25%, respectively. The horizontal axis corresponds to different annualized autocorrelations, ρ_B^4, of the debt-to-output ratio, B^G/Y; the higher the autocorrelation, the lower the speed of repayment. Welfare costs are calculated as in Lucas (1987).

$p(\theta^{-1}) - p^{zd}(\theta^{-1})$ (%)

- - ◇ - Weak
— □ — Strong

Faster ← Repayment → Slower

$\tilde{E}(\epsilon)$

Faster ← Repayment → Slower

$\tilde{E}(\epsilon_G)$

Annualized ACF$_1(B^G/Y)$, ρ_B^4

$\sigma(\Lambda^U)/E(\Lambda^U)$

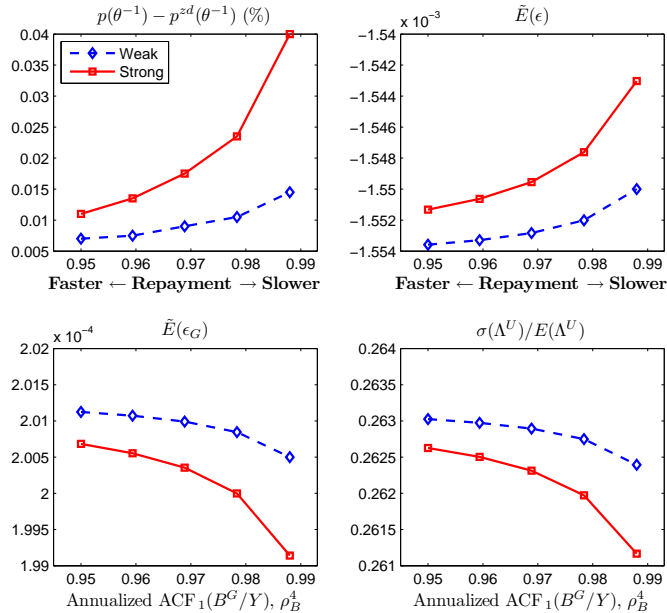Annualized ACF$_1(B^G/Y)$, ρ_B^4

Figure 7: Pessimistic Distortions and Tax-smoothing

Notes - This figure shows detection error probabilities, pessimistic distortions and market price of uncertainty as a function of the policy parameters ϕ_B and ρ_B. All other parameters are calibrated to the values used in Tables 1. The two lines reported in each plot are associated to different levels of intensity of the countercyclical fiscal policy described in equation (19). 'Weak' and 'Strong' policies are generated by calibrating ϕ_B to 0.1% and 0.25%, respectively. Horizontal axis corresponds to different annualized autocorrelation, ρ_B^4, of debt to output ratio, B^G/Y; the higher the autocorrelation, the lower the speed of repayment.

attention to short-run stabilization may be questionable.

5. Conclusion

Most of the literature in macroeconomics and growth assumes that agents know the true probability distribution of future fiscal policy instrument dynamics. In this paper, in contrast, we introduce concerns for robustness as in Hansen and Sargent (2007)) in an endogenous growth model in which fiscal

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policy can alter both short- and long-run economic dynamics.

We show that common countercyclical deficit policies which are welfare-enhancing with time-additive CRRA preferences can turn into a source of large welfare losses when agents have concerns for robustness. The reason is that there is a relevant trade-off between model uncertainty and long-run profit risks. Reducing short-run uncertainty through persistent public deficits or surpluses can reduce pessimistic distortions, but at the cost of bringing about more risk for long-run profits.

Future research should integrate business cycle considerations into our model and study the optimality of multiple tax instruments. Furthermore, it will be important to study the optimal interaction between monetary and fiscal policy over both the short- and the long-run. Finally, our model abstracts from financial and labor market frictions. Whether these elements could increase or reduce the performance of standard countercyclical deficit policies with robustness is a question that we leave for future research.

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Appendix: Solution Method and Welfare Costs

Solution Method and Computations. We solve the model in `dynare++4.2.1` using a third-order approximation. The policies are centered about a fix-point that takes into account the effects of volatility on decision rules. In the **.mat** file generated by `dynare++` the vector with the fix-point for all our endogenous variables is denoted as `dyn_ss`. All conditional moments are computed by means of simulations with a fixed seed to facilitate the comparison across fiscal policies.

Welfare Costs. Consider two consumption bundle processes, $\{u^1\}$ and $\{u^2\}$. We express welfare costs as the additional fraction λ of lifetime consumption bundle required to make the representative agent indifferent between $\{u^1\}$ and $\{u^2\}$:

$$U_0(\{u^1\}) = U_0(\{u^2\}(1+\lambda)).$$

Since we specify U so that it is homogenous of degree one with respect to u, the following holds:

$$\frac{U_0(\{u^1\})}{u_0^1} \cdot u_0^1 = \frac{U_0(\{u^2\})}{u_0^2} \cdot u_0^2 \cdot (1+\lambda).$$

This shows that the welfare costs depend both on the utility-consumption ratio and the initial level of our two consumption profiles. In our production economy, the initial level of consumption is endogenous, so we cannot choose it. The initial level of patents, $A_0^i \quad i \in \{1,2\}$, in contrast, is exogenous:

$$\frac{U_0(\{u^1\})}{u_0^1} \cdot \frac{u_0^1}{A_0^1} \cdot A_0^1 = \frac{U_0(\{u^2\})}{u_0^2} \cdot \frac{u_0^2}{A_0^2} \cdot A_0^2 \cdot (1+\lambda).$$

We compare economies with different tax regimes, but the same initial condition for the stock of patents: $A_0^1 = A_0^2$. After taking logs, evaluating utility– and consumption–productivity ratios at their unconditional mean, and imposing $A_0^1 = A_0^2$, we obtain the following expression:

$$\lambda \approx \overline{\ln U^1/A} - \overline{\ln U^2/A},$$

where the bar denotes the unconditional average which is computed using the `dyn_ss` variable in `dynare++`.