Fiscal Policy and the Distribution of Consumption Risk*

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Abstract

Recent fiscal interventions have raised concerns about U.S. public debt, future fiscal pressure, and long-run economic growth. This paper studies fiscal policy design in an economy in which (i) the household is averse to both short- and long-run uncertainty, and (ii) growth is endogenously sustained through innovations whose market value depends on the tax system. By reallocating tax distortions through debt, fiscal policy alters both the composition of intertemporal consumption risk and the incentives to innovate. Tax policies aimed at short-run stabilization may substantially increase long-run tax and growth uncertainty and ultimately reduce both average growth and welfare.

Keywords: Fiscal Policy, Endogenous Growth Risk, Asset Prices.
JEL Classification: E62, G1, H2, H3.

1 Introduction

Since the onset of the fall 2008 financial crisis, the world has witnessed government interventions on a unprecedented scale aimed at preventing a major global depression. While the return of the world economy to positive growth suggests that these policies may have been successful at short-run stabilization, their long-term effects are still uncertain.

Indeed, sharp increases in projected government debt go hand in hand with such fiscal stimulus packages. The 2012 Congressional Budget Office Outlook, for example, suggests that the US debt-output ratio may follow an unstable path in the coming years, reaching as high as 200% within the next three decades. These forecasts raise considerable uncertainty about the future stance of fiscal policy required for debt stabilization. Given the distortionary nature of tax instruments, current deficits may have substantial effects on the long-term prospects of the economy. In particular, short-run economic stabilization may come at the cost of dimmer and uncertain long-term growth.

In this paper, we examine fiscal policy design in an environment in which the government faces an explicit trade-off between short-run stabilization and long-run growth. As in Barro (1979), our proposed government finances an exogenous expenditure stream through a mix of taxes and non-contingent debt. Government expenditure is stochastic and only labor income taxes are available, as in Lucas and Stokey (1983). We extend this classic benchmark through two relevant economic mechanisms.

On the technology side, our economy grows at an endogenous and stochastic rate determined by firms' incentives to innovate (Romer 1990). By altering labor supply through tax dynamics, fiscal policy can affect the market value of innovative products and ultimately long-run growth.

On the household side, we adopt the recursive preferences of Epstein and Zin (1989) and Weil (1989, 1990) so that agents care about the intertemporal distribution of growth risk, as in Barsky and DeLong (1993) and Bansal and Yaron (2004). Specifically, agents are sensitive to the timing of taxation because they are averse to tax policies that amplify long-run growth risk.

In this setting, the government's financing policy effectively serves as a device to reallocate consumption risk across different horizons. We find that tax smoothing is welfare enhancing if it is oriented toward long-run stabilization. Tax policies promoting short-run stabilization, in contrast,

increase long-run risk and depress both average growth and welfare. We thus identify a relevant and novel tension between short-run stabilization and long-term growth.

Our results are driven by two complementary channels that reinforce each other and enrich the welfare implications of common tax smoothing prescriptions. In the Lucas and Stokey (1983) economy, the cost of future tax distortions can be summarized exclusively by their effect on short-run consumption growth (the short-run consumption smoothing margin). In our setting, in contrast, we need to consider both an asset price and an intertemporal distortion margin.

The asset price channel is related to endogenous growth. In a stochastic version of the Romer (1990) economy, indeed, growth depends on the risk-adjusted present value of expected future profits. In our setting, the tax system can directly affect long-term growth by altering the risk characteristics of both profits and the consumption-based discount factor. Equivalently, the shadow cost of future tax distortions depends also on its impact on the market value of patents.

Since with standard time-additive preferences agents are sensitive to short-run growth risk only, tax smoothing oriented toward short-run stabilization produces welfare benefits through both the short-run consumption-smoothing and the asset price channels. That is, welfare improves because of both lower short-run volatility in consumption and higher average growth. With standard preferences, therefore, there is no tension between long-term growth and short-run stabilization.

With recursive preferences, however, the entire intertemporal distribution of future tax distortions becomes welfare relevant, as news about future long-run taxation affects continuation utility. This implicit preference for the timing of taxation stems from the intertemporal distortion margin. When agents have a preference for early resolution of uncertainty, they care about continuation utility smoothing in addition to consumption smoothing. Since continuation utility reflects expected long-run consumption, the tax system should take into account long-run consumption stabilization.

In contrast to the time-additive case, we show that short-run-oriented tax smoothing can produce substantial welfare costs as high as of 1.5% of lifetime consumption. Intuitively, upon the realization of adverse exogenous shocks the use of deficits can reduce the short-run drop in output and consumption, but the subsequent financing needs associated with long-run budget balancing produce bad news about future distortionary taxation. When tax distortions endogenously affect growth rates, this leads to more uncertainty about long-term growth prospects. Hence, in asset

pricing language, a reduction in the extent of short-run growth risk comes at the cost of increased exposure to long-run risk. We view these results as quantitatively significant, as our model is calibrated to reproduce key features of both consumption risk premia and wealth-consumption ratios as measured by Lustig et al. (2013) and Alvarez and Jermann (2004).

Under aversion to long-run uncertainty, the reallocation of consumption risk from the short- to the long-run can further depress welfare because of the asset price channel. With recursive preferences, indeed, the agent prices both short- and long-run profit risk. By increasing long-run growth risk, short-run-oriented fiscal policies lead to a drop in the market value of patents, research and development (R&D) investment, and growth. This interaction between the asset-price and intertemporal-distortion channels explains both (i) our high welfare costs for fiscal policies aimed at short-term stabilization and (ii) the sizeable benefits created by policies seeking to stabilize long-term growth prospects by responding to asset prices and their determinants.

At a broader level, our study conveys the need to introduce risk considerations into the current fiscal policy debate. More precisely, our analysis suggests that asset prices should be an important determinant of tax systems and that long-term risk considerations should be included in fiscal policy design. In an economy with uncertain growth, ignoring the timing of taxes and the implied intertemporal composition of consumption risk can substantially bias the welfare cost-benefit analysis of fiscal interventions. Our risk-based endogenous growth model shows a relevant and novel tension between short-run stabilization and long-term growth that has not been highlighted before. We show that the fiscal debate, rather than focusing exclusively on the average level of taxation, should be concerned with long-term tax uncertainty as well, since tax risk can be as welfare-relevant as average tax pressure.

Our study highlights relevant costs associated with short-term oriented financing policies, but it abstracts away from various channels through which fiscal intervention may generate significant welfare benefits. Even though our analysis is silent about the net welfare effects of fiscal intervention, our quantitative results suggest that these financing costs are economically relevant.

The remainder of this paper is organized as follows. In the next section we discuss related literature. We present our model in section 2, summarize our calibration strategy in section 3, and discuss the quantitative results in sections 4 and 5. In section 6 we show that our results are robust

to the introduction of subsidies. Section 7 concludes.

1.1 Related Literature

Our objective is to quantify the welfare implications of long-run tax uncertainty and tax smoothing in an equilibrium asset pricing model in which growth is sensitive to the tax system.

Barlevy (2004) finds that the costs of business cycles can be substantial in stochastic models with endogenous growth. We differ from this important contribution in two respects. First, we explicitly consider fiscal stabilization in a risk-sensitive framework. Secondly, since we adopt recursive preferences, the intertemporal reallocation of consumption risk is central to our results.

Jones et al. (1993) also consider fiscal policy in an endogenous growth model, but they analyze accumulation of human capital and abstract away from uncertainty and asset pricing considerations. Chugh and Ghironi (2010) examine fiscal policy in a model with endogenous expanding variety but consider neither endogenous growth nor the risk and preference channels we emphasize. In contrast to these papers, we focus on noncontingent debt policies in the spirit of Aiyagari et al. (2002) and Sleet and Yeltekin (2006).

Risk premia are a critical element of our study as well. In this respect, our analysis is closely related to the work of Tallarini (2000) and Alvarez and Jermann (2004, 2005), who link the welfare costs of aggregate consumption fluctuations to asset prices. We differ from them in that we explicitly consider the welfare implications of government policies and link them to the market value of innovation and the intertemporal distribution of consumption risk. Our results are also consistent with the empirical consumption risk premia estimated by Lustig et al. (2013).

Recently, several studies have focused on evaluating fiscal policies in asset pricing settings. Gomes et al. (2010) calculate the distortionary costs of government bailouts in a model that is consistent with basic asset market data. Panageas (2010a, b) studies taxation and the incentive to manage risk in the presence of public bailouts and liquidation costs. Gomes et al. (2012b) analyze fiscal policies in an incomplete markets economy with heterogeneous agents. Gomes et al. (2012a) and Pastor and Veronesi (2012, 2011) examine the effects of policy uncertainty on economic outcomes and stock returns.

Berndt et al. (2012) and Lustig et al. (2008) examine the government's ability to hedge fiscal

shocks. They abstract away from the endogenous technological progress highlighted in Kung and Schmid (2012), Papanikolaou (2011), Garleanu et al. (2011), Garleanu et al. (2012), Kogan et al. (2012a), and Kogan et al. (2012b). None of these papers addresses taxation and welfare costs in a long-term risk-sensitive environment similar to ours.

In practice, we quantitatively examine the significance of fiscal risk channels by means of simple and implementable rules linking fiscal policy stance to macroeconomic conditions, in the spirit of Dotsey (1990), Ludvigson (1996), Schmitt-Grohe and Uribe (2005, 2007), Davig et al. (2010), Leeper et al. (2010), Bi and Leeper (2010). In contrast to these papers, our fiscal rules account for asset prices and expectations of future tax distortions in the spirit of the monetary policy studies of Gallmeyer et al. (2005, 2011). We see our tax-smoothing policies as devices to quantitatively trace the risk trade-off frontier faced by the fiscal authority. This is an important contribution, since with non-time-separable preferences the quantitative assessment of optimal fiscal policies is challenging, even in much simpler economic setups (Karantounias 2011, 2012).

In a companion paper, Croce et al. (2012), we provide an application of our framework in the special case of robustness (Hansen and Sargent 2009).[1] In the present manuscript we provide a broad and general analysis of the interaction between risk preferences and fiscal policy design. Specifically, we show that the benefits of stabilization are horizon-dependent and are crucially related to the term structure of growth risk. Furthermore, we show that our stabilization results do not hinge on market failures and remain significant even after introducing appropriate subsidy policies.

2   Model

We use a stochastic version of the Romer (1990) model in which the fiscal system affects all moments of the distribution of consumption growth, including its unconditional mean. Since our representative agent has recursive preferences, she cares about the intertemporal composition of consumption risk and is sensitive to both current and future taxation. Even though stylized, our model enables us to conduct a rich and detailed quantitative analysis of the link between growth

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[1]Croce et al. (2012) has been solicited for the Carnagie-Rochester-NYU Conference Series on Public Policy 'Robust Macroeconomic Policy'.

risk and fiscal dynamics.

On the production side, the only source of sustained growth in the economy is the accumulation of patented intermediate goods (henceforth patents) that facilitate the production of a final consumption good. Patents are created through an innovation activity requiring investment in research and development (R&D) and can be stored. In this model, therefore, patents represent an endogenous stock of intangible capital. For simplicity, we abstract away from both tangible capital accumulation and capital taxation and allow the government to finance its expenditures only by a mix of deficit and labor income taxes, as in Lucas and Stokey (1983).

In this class of models, the speed of patent accumulation, i.e., the growth rate of the economy, depends on the risk-adjusted present value of the additional cash-flow stream generated by such innovations. The fiscal system affects growth through two channels. First, by distorting the labor supply through taxation, fiscal policy affects future expected profits (the cash-flow channel). Second, since we assume that the representative household has Epstein-Zin preferences, the market value of a patent is sensitive to both short-run and long-run risk adjustments (the discount rate channel). Asset pricing considerations are therefore required to understand the impact of a given tax system on the equilibrium growth rate of the economy.

Specifically, we show that smoothing distortional taxation using public debt affects the riskiness of patents' cash flow over both the short and long horizons, thereby altering the equilibrium growth rate of the economy. In this sense, choosing a tax system is equivalent to choosing a specific intertemporal distribution of growth risk.

In what follows, we start by describing the household's problem, the production sector, and the government and fiscal policy. We then provide a description of the equilibrium link between asset prices and aggregate growth.

2.1 Household

The representative household has Epstein and Zin (1989) preferences,

$$U_t = \left[(1-\beta)u_t^{1-\frac{1}{\psi}} + \beta(\mathbb{E}_t U_{t+1}^{1-\gamma})^{\frac{1-\frac{1}{\psi}}{1-\gamma}} \right]^{\frac{1}{1-\frac{1}{\psi}}}, \tag{1}$$

defined over a CES aggregator, u_t, of consumption, C_t, and leisure, $1 - L_t$:

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

We let L_t, γ, ψ, and ν denote labor, relative risk aversion (RRA), intertemporal elasticity of substitution (IES), and degree of complementarity between leisure and consumption, respectively. Leisure is multiplied by A_t, our measure of standards of living, to guarantee balanced growth when $\nu \neq 1$.

When $\psi = \frac{1}{\gamma}$, these preferences collapse to the standard time-additive CRRA case. When, instead, $\psi \neq \frac{1}{\gamma}$, the agent cares about the timing of the resolution of uncertainty, meaning that long-run growth news affects her marginal utility differently than does short-run growth news. In what follows, we always assume that $\psi \geq \frac{1}{\gamma}$ so that when the agent cares about the intertemporal composition of consumption risk, she dislikes uncertainty about the long-run growth prospects of the economy.

In each period, the household chooses labor; consumption; equity shares, Z_{t+1}; and public debt holdings, B_t; to maximize utility according to the following budget constraint:

$$C_t + Q_t Z_{t+1} + B_t = (1 - \tau_t)W_t L_t + (Q_t + D_t)Z_t + B_{t-1}(1 + r_{t-1}^f), \tag{2}$$

where D_t denotes aggregate dividends (to be specified in equation (21)), Q_t is the market value of an equity share, and r_t^f is the the short-term risk-free rate. Wages, W_t, are taxed at a rate τ_t.

In our setup the stochastic discount factor in the economy is given by

$$M_{t+1} = \beta \left(\frac{u_{t+1}}{u_t} \right)^{\frac{1}{\nu} - \frac{1}{\psi}} \left(\frac{C_{t+1}}{C_t} \right)^{-1/\nu} \left(\frac{U_{t+1}^{1-\gamma}}{\mathbb{E}_t[U_{t+1}^{1-\gamma}]} \right)^{\frac{1/\psi - \gamma}{1-\gamma}}, \tag{3}$$

where the last factor captures aversion to continuation utility risk, i.e., long-run growth risk. Optimality implies the following asset pricing conditions:

$$
\begin{aligned}
Q_t &= \mathbb{E}_t[M_{t+1}(Q_{t+1} + D_{t+1})] \\
\frac{1}{1 + r_t^f} &= \mathbb{E}_t[M_{t+1}].
\end{aligned}
$$

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In equilibrium, the representative agent holds the entire supply of both bonds and equities. The latter is normalized to be one, i.e., $Z_t = 1 \quad \forall t$. The intratemporal optimality condition on labor takes the following form:

$$\frac{1 - \theta_c}{\theta_c} A_t^{(1-1/\nu)} \left(\frac{C_t}{1 - L_t} \right)^{1/\nu} = (1 - \tau_t) W_t \tag{4}$$

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

2.2 Production

The production process involves three sectors. The final consumption good is produced in a competitive sector using labor and a bundle of intermediate goods. Intermediate goods are produced by firms that have monopoly power and hence realize positive profits. Intermediate good producers use these rents to acquire the right of production from innovators. Innovators create new patents through R&D investment and are subject to a free-entry condition.

Final good Firm. A representative and competitive firm produces the economy's single final output good, 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:

$$Y_t = \Omega_t L_t^{1-\alpha} \left[\int_0^{A_t} X_{it}^\alpha \, di \right], \tag{5}$$

where Ω_t denotes the 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.

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

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

where P_{it} is the price of intermediate good i at time t. Profit maximization thus implies

$$
\begin{aligned}
X_{it} &= L_t \left(\frac{\Omega_t \alpha}{P_{it}} \right)^{\frac{1}{1-\alpha}}, \\
W_t &= (1-\alpha) \frac{Y_t}{L_t}.
\end{aligned}
\tag{6}
$$

Intermediate good firms.   Each intermediate good $i \in [0 \quad A_t]$ is produced by a 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 and equal to one. Taking the demand schedule of the final good producer (equation (6)) as given, each firm chooses its price, P_{it}, to maximize the following operating 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 obtsin

$$
\begin{aligned}
X_{it} &\equiv X_t = L_t (\Omega_t \alpha^2)^{\frac{1}{1-\alpha}}, \\
\Pi_{it} &\equiv \Pi_t = (\frac{1}{\alpha} - 1) X_t.
\end{aligned}
\tag{7}
$$

In view of this symmetry, in what follows we drop the subscript i. Equations (5) and (7) allow us to express final output in the following compact form:

$$
Y_t = \frac{1}{\alpha^2} A_t X_t = \frac{1}{\alpha^2} A_t L_t (\Omega_t \alpha^2)^{\frac{1}{1-\alpha}}.
\tag{8}
$$

Since both labor and productivity are stationary, equation (8) implies that the long-run growth rate of output is determined by the expansion of the variety of intermediate goods, A_t. This expansion stems from endogenous innovation conducted in the R&D sector, which we describe next.

9

Research and development. Innovators develop blueprints for new intermediate goods 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 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:

$$V_t = \Pi_t + (1-\delta)E_t\left[M_{t+1}V_{t+1}\right]. \tag{9}$$

Let $1/\vartheta_t$ be the cost of producing a new variety. The free-entry condition in the R&D sector implies that at the optimum

$$\frac{1}{\vartheta_t} = E_t\left[M_{t+1}V_{t+1}\right], \tag{10}$$

i.e., the cost of producing a variety must equal the market value of the new patents. Equation (10) is central in this class of models because it implicitly pins down the optimal level of investment in R&D, S_t, and ultimately the growth rate of the economy.

Specifically, our stock of patents, A_t, evolves as follows:

$$A_{t+1} = \vartheta_t S_t + (1-\delta)A_t, {}^{[2]} \tag{11}$$

and hence

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

Similarly to Comin and Gertler (2006), we assume that the innovation technology ϑ_t involves a congestion externality effect capturing decreasing returns to scale in the innovation sector,

$$\vartheta_t = \chi\left(\frac{S_t}{A_t}\right)^{\eta-1} \qquad \eta \in (0,1), \tag{12}$$

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[2]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 (10) and (11) must to be replaced by $A_{t+1} = (1-\delta)(\vartheta_t S_t + A_t)$ and $\frac{1}{\vartheta_t} = E_t\left[M_{t+1}(1-\delta)V_{t+1}\right]$, respectively. Our results are not sensitive to this modeling choice.

where $\chi > 0$ is a scale parameter and $\eta \in [0,1]$ is the elasticity of new intermediate goods with respect to R&D. This specification captures 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 (10)–(12), we obtain the following optimality condition for investment in R&D:

$$\frac{1}{\chi}\left(\frac{S_t}{A_t}\right)^{1-\eta} = E_t\left[\sum_{j=0}^{\infty} M_{t+j|t}(1-\delta)^j \Pi_{t+j}\right],\tag{13}$$

where $M_{t+j|t} \equiv \prod_s^j M_{t+s|t}$ is the j-steps-ahead pricing kernel and $M_{t|t} \equiv 1$. Equation (13) suggests that the amount of innovation intensity in the economy, S_t/A_t, is directly related to the discounted value of future profits. When agents expect profits above (below) steady state, they have an incentive to invest more (less) in R&D, ultimately boosting (reducing) long-run growth. In section 2.5, we further discuss this point, since it is essential to the understanding of long-term stabilization.

2.3   Government

Expenditure to be financed.   The government faces an exogenous and stochastic expenditure stream, G_t, that evolves as follows:

$$\frac{G_t}{Y_t} = \frac{1}{1 + e^{-gy_t}},\tag{14}$$

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 $G_t \in (0, Y_t) \quad \forall t$, and it enables us to replicates key features of the expenditure-to-output ratio observed in the U.S. data. In most of our analysis, we focus only on the expenditure component of total public liabilities and abstract away from entitlements. Results reported in Appendix A suggest that adding further liabilities in the form of lump-sum transfers to the household would enhance our results.

Financing rules. 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:

$$B_t = (1 + r_{f,t-1})B_{t-1} + G_t - T_t, \tag{15}$$

with

$$B_0 = 0.$$

The government chooses the mix between taxation and deficit by means of simple, implementable and plausible fiscal rules, in the spirit of Favero and Monacelli (2005), Schmitt-Grohe and Uribe (2007), Bi and Leeper (2010), and Leeper et al. (2010).

We focus on two tax regimes. Under the first regime, 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, there is no tax smoothing and the tax rate perfectly mimics the properties of our exogenous government expenditure process. We take this zero-deficit policy as a benchmark case in our welfare analysis.

Under the second regime, we allow for tax smoothing and let the government adjust its fiscal stance according to prevailing macroeconomic conditions. We focus on two aspects of tax smoothing, namely the persistence and intensity of swings in the tax rate. We specify the government's policy in terms of a debt management rule, with tax rates implied by the budget constraint, as follows:

$$\frac{B_t}{Y_t} = \rho_B \frac{B_{t-1}}{Y_{t-1}} + \phi_B \cdot \epsilon_t^B, \tag{16}$$

where ϵ_t^B is an endogenous, stationary, and zero-mean variable summarizing the state of the economy; ϕ_B determines the intensity of the government response to shocks; and $\rho_B \in (0, 1)$ is a measure of the speed of repayment of debt, i.e., the higher the value of ρ_B, the slower the repayment of debt

relative to output.[3]

This parsimonious specification has two main advantages. First, the condition $\rho_B < 1$ guarantees stationarity of the debt-output ratio. In the language of Bi and Leeper (2010), our rule in equation (16) anchors expectations about future debt and rules out unstable paths. Overall, this specification replicates key empirical properties of the U.S. debt-output ratio.

Second and most importantly, the tax system is fully characterized by just two parameters, (ρ_B, ϕ_B). To better illustrate this point, we combine equations (15) and (16) to obtain the following expression for the tax rate:

$$\tau_t(\rho_B, \phi_B) = \tau_t^{zd} - \phi_B \frac{\epsilon_t^B}{1-\alpha} + \frac{1}{1-\alpha} \left(\frac{1 + r_{f,t-1}}{Y_t/Y_{t-1}} - \rho_B \right) \frac{B_{t-1}}{Y_{t-1}}. \tag{17}$$

The second term on the right-hand side of this equation refers to the departure of the tax rate from its zero-deficit counterpart in response to economic shocks. The parameter ϕ_B determines the intensity of this response. The last term in equation (17), in contrast, captures the persistent effect that debt repayment has on taxes. This term generates a positive monotonic mapping between ρ_B and the persistence of the tax rate, i.e., choosing a higher ρ_B is equivalent to increasing the degree of tax smoothing.

Tax smoothing horizons.   In our analysis, we consider two different specifications for ϵ_t^B. We first focus on the case in which the government uses tax smoothing to reduce short-run fluctuations in labor. In this case, we set

$$\epsilon_t^B \equiv \log L_{SS} - \log L_t, \tag{18}$$

where L_{SS} denotes the steady-state level of labor. Under this specification, 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. As we show in the next section, reducing short-run labor volatility implies a reduction of the short-run volatility of the whole consumption bundle. For this reason, we refer to this specification as *short-run-oriented* tax smoothing.

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[3]Given this policy specification, we have $E[B_t] = B_0 = 0$. In our analysis, we abstract away from a non-zero target for the debt-output ratio.

Under our second specification, in contrast, we consider a government concerned about stabilizing the economy's long-term growth prospects. In our innovation-driven model of endogenous growth, long-term growth closely mirrors the dynamics of investment in R&D, S_t. As suggested by equation (13), long-run stabilization can be achieved by responding to fluctuations in expected profits. In particular, we set

$$\epsilon_t^B \equiv E_t[\Delta \log A_{t+1}\Pi_{t+1}] - \Delta \log A\Pi_{SS}, \tag{19}$$

so that when expected aggregate profit growth is below average the government increases current taxation in order to create expectations of lower future tax rates. Under this policy, therefore, the government counterbalances bad long-run profit news with good long-run tax rate news. We refer to this specification as *long-run-oriented* tax smoothing.

2.4 Market Clearing

We complete the description of our model by discussing our market clearing conditions. In the labor market, the following holds:

$$\left(\frac{C_t}{A_t(1 - L_t)}\right)^{1/\nu} = (1 - \tau_t(\rho_B, \phi_B))\frac{(1 - \alpha)Y_t}{A_t L_t}. \tag{20}$$

The market clearing condition for the final good is given by

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

implying that final output is used for consumption, R&D investment, production of intermediate goods, and public expenditure.

Given the multisector structure of the model, various assumptions on the constituents of the stock market can be adopted. We assume that the stock market is a claim to the net payout from 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:

$$D_t = \Pi_t A_t - S_t. \tag{21}$$

2.5 Growth, Asset Prices, and Risk Distribution

Growth and asset prices. Combining equations (10)–(13), we obtain the following expression
for growth rate in the economy:

$$
\begin{aligned}
\frac{A_{t+1}}{A_t} &= 1 + \delta + \chi^{\frac{1}{1-\eta}} E_t \left[M_{t+1} V_{t+1} \right]^{\frac{\eta}{1-\eta}} \\
&= 1 + \delta + \chi^{\frac{1}{1-\eta}} E_t \left[\sum_{j=1}^{\infty} M_{t+j|t} (1-\delta)^{j-1} \left(\frac{1}{\alpha} - 1 \right) (\Omega_{t+j} \alpha^2)^{\frac{1}{1-\alpha}} L_{t+j} \right]^{\frac{\eta}{1-\eta}}.
\end{aligned}
\tag{22}
$$

The relevance of equation (22) is twofold, as it enables us to discuss both the interaction between
recursive preferences and endogenous growth, and the role played by the tax system.

First, we point out that in this framework, growth is a monotonic transformation of the dis-
counted value of future profits. This implies that the average growth in the economy is endogenously
negatively related to both the discount rate used by the household and the amount of perceived
risk. When the household has standard time-additive preferences, only short-run profit risk matters
for the determination of the value of a patent. When the agent has recursive preferences, however,
optimal growth depends also on the endogenous amount of volatility in expected long-run profits.
A characterization of the entire intertemporal distribution of risk is required.

Second, since profits are proportional to labor, and labor supply is sensitive to the tax rate
(equation (20)), a fiscal system (ϕ_B, ρ_B) based on tax smoothing ultimately introduces long-lasting
fluctuations in future profits. Depending on the dynamic properties of current and future taxes,
tax smoothing can depress or enhance long-term growth and ultimately welfare.

Our study shows that in an economy calibrated to match key asset pricing facts, short-run-
oriented tax smoothing comes at the cost of reduced long-run growth, whereas long-run-oriented
tax smoothing can produce benefits. This tension is at the core of our welfare analysis.

15

A simple log-linear environment. We find it useful to study the asset pricing properties of both patent value and pricing kernel in a simple log-linear setting. This analysis provides simple economic intuition on the impact of both recursive preferences and tax uncertainty on long-run growth. To this aim, assume for the momnet that log profits, $\ln \Pi_t$, and log consumption bundle growth, Δc_t, are jointly linear-gaussian and embody a predictable component:

$$
\begin{aligned}
\Delta c_{t+1} &= \mu + x_{c,t} + \sigma_c^{SR} \varepsilon_{t+1}^c \\
\ln \Pi_{t+1} &= \overline{\Pi} + x_{\Pi,t} + \sigma_{\Pi}^{SR} \varepsilon_{t+1}^{\pi} \\
x_{c,t+1} &= \rho_c x_{c,t} + \sigma_c^{LR} \varepsilon_{t+1}^{xc} \\
x_{\Pi,t+1} &= \rho_{\Pi} x_{\Pi,t} + \sigma_{\Pi}^{LR} \varepsilon_{t+1}^{x\Pi} \\
\varepsilon_{t+1} &\equiv \begin{bmatrix} \varepsilon_{t+1}^c & \varepsilon_{t+1}^{\pi} & \varepsilon_{t+1}^{xc} & \varepsilon_{t+1}^{x\Pi} \end{bmatrix} \sim i.i.d.N.(\overrightarrow{0}, \Sigma),
\end{aligned}
\tag{23}
$$

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 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 approximate solution for the pricing kernel:

$$
\ln \Lambda_{t+1} - E_t[\ln \Lambda_{t+1}] = \begin{cases} -\gamma \sigma_c^{SR} \varepsilon_{t+1}^c & \text{CRRA} \\ -\gamma \sigma_c^{SR} \varepsilon_{t+1}^c - \kappa_c \frac{\gamma - 1/\psi}{1 - \rho_c \kappa_c} \sigma_c^{LR} \varepsilon_{t+1}^{xc} & \gamma \neq 1/\psi, \end{cases}
\tag{24}
$$

where $\kappa_c = \overline{P/C}/(1-\overline{P/C})$ is an approximation constant and P/C is the average wealth-consumption ratio. 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:

$$
r_{V,t+1} - E_t[r_{V,t+1}] \approx \kappa_2 \sigma_{\Pi}^{SR} \epsilon_{t+1}^{\Pi} - \frac{\kappa_1}{1 - \kappa_1 \rho_c} \sigma_c^{LR} \epsilon_{t+1}^{xc} + \frac{\kappa_2}{1 - \kappa_1 \rho_{\Pi}} \sigma_{\Pi}^{LR} \epsilon_{t+1}^{x\Pi},
\tag{25}
$$

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 recursive 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 sufficiently high values of $\gamma - 1/\psi$, growth is pinned down mainly by long-run consumption risk, as opposed to short-run risk.

Third, in contrast to the endowment economy of Bansal and Yaron (2004), in our setting all cash-flow parameters are endogenous objects sensitive to the fiscal system (ϕ_B, ρ_B). After calibrating the model, we explore the role of ϕ_B and ρ_B in (i) varying the amount of short- and long-run risk, and (ii) altering long-run growth.

Link to optimal policy. In Appendix B, we report the Ramsey problem associated with our economy. In order to reduce the set of constraints faced by the planner, we assume availability of state-contingent debt. Croce et al. (2013) provide sufficient conditions for the existence of a well-defined Ramsey problem, but they do not assess the trade-offs faced by Ramsey. With recursive preferences, the multiplier on the promise-keeping constraint is an endogenous state that evolves as a log-martingale whose characterization is challenging even in simpler settings (Karantounias 2011, 2012). Our exogenous fiscal policy rules, in contrast, are a simple and useful device to trace the risk trade-off frontier faced by the government in our rich production setting.

Specifically, in our setting the marginal utility of consumption from a Ramsey perspective, λ_t, can be decomposed in the following way:

$$\lambda_t = \lambda_t^{LS} \cdot \underbrace{M_t^{\frac{\zeta}{\zeta-1}} + u_{ct}\xi_t - M_t^{\frac{\zeta}{\zeta-1}}}_{\text{Intertemporal Distorsion Channel}} \cdot u_{cc,t}\Phi \underbrace{(\rho_t - \rho_{t-1}\vartheta_{t-1}V_t - D_t)}_{\text{Asset Price Channel}}, \quad (26)$$

where $\lambda_t^{LS} := u_{ct} + \Phi\Omega_{c,t}$ is the shadow value of consumption in the Lucas and Stokey (1983) economy, $D_t := A_t\Pi_t - S_t$ are the aggregate dividends, and ξ_t evolves as a martingale with respect

to $\pi_t M_t$ with $\xi_0 = 0$ and $\mathrm{StD}_t[\xi_{t+1}] \propto \zeta$.

Relative to Lucas and Stokey (1983), our setup adds two margins. The first margin concerns the second term in equation (26) and accounts for the impact that current taxation has on future utility (the intertemporal distortion margin). In our risk-based analysis, the term has a simple interpretation: it defines the link between short-run consumption smoothing and continuation utility smoothing that arises under recursive preferences. Since continuation utility is a reflection of future expected consumption, this term introduces a tension between short-run and long-run consumption stabilization. This term enables us to meaningfully interpret fiscal policy as a device to alter the intertemporal distribution of consumption risk.

The second margin relates to the last term in equation (26) and arises because of endogenous growth. This term captures the impact that future labor taxation distortions have on the riskiness of future labor supply, profits, and the market value of innovation (the asset price channel). Consistent with our analysis of equation (22), assessment of the impact of taxation on the value of patents is essential to the understanding of long-term growth.

Intuitively, for any given tax system, the planner takes into account both the asset-price and the intertemporal-distortion channel trying to balance short-run consumption smoothing, long-run consumption stabilization, and growth. In our setup, these two channels are complementary and reinforce each other in the determination of novel and rich fiscal policy implications, which we discuss next.

3 Calibration

We report our benchmark calibration along with the implied main statistics of our model in table 1. Our benchmark calibration refers to the case of a zero-deficit policy. Since the main focus of the paper is on the implications of fiscal policy for long-run consumption dynamics, we calibrate our productivity process to match the unconditional volatility of consumption growth observed in the U.S. over the long sample 1929–2008.

The parameters for the government expenditure-output ratio are set to have an average share of 10% and an annual volatility of 4%, consistent with U.S. annual data over the sample 1929–

Table 1 - Calibration and Main Statistics

Panel A: Parameters		
Description	Symbol	Value
Preference Parameters		
Consumption-Labor Elasticity	ν	0.7
Utility Share of Consumption	θ_c	0.095
Discount Factor	β	0.996
Intertemporal Elasticity of Substitution	ψ	1.7
Risk Aversion	γ	7
Technology Parameters		
Elasticity of Substitution Between Intermediate Goods	α	0.7
Autocorrelation of Productivity	ρ	0.96
Scale Parameter for R&D Externalities	χ	0.45
Survival Rate of Intermediate Goods	$1 - \delta$	0.97
Elasticity of New Varieties wrt R&D Investment	η	0.8
Standard Deviation of Technology Shock	σ	0.006
Government Expenditure Parameters		
Log-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

Panel B: Moments		
	Data	Model
$E(\Delta c)$ (%)	2.05	2.04
$\sigma(\Delta c)$ (%)	2.34	2.14
$ACF_1(\Delta c)$	0.44	0.58
$E(L)$ (%)	33.0	35.63
$E(\tau)$ (%)	33.5	33.5
$\sigma(\tau)$ (%)	3.10	1.80
$E(r_f)$	0.93	1.48
$\sigma(m)$	–	0.43
$E(r^C - r_f)$	–	1.89

Notes - This table reports the benchmark quarterly calibration of our model along with the main moments computed under the zero-deficit policy ($\phi_B = 0$). $E(L)$ is the fraction of hours worked. All moments are annualized. All figures are multiplied by 100, except $ACF_1(\Delta c)$, the first-order autocorrelation of consumption growth. The log discount factor is denoted by m, and τ is the tax rate. r^C and r_f are the return of the consumption claim and the risk-free bond, respectively.

2008. Using post–World War II data would make expenditure risk even larger; hence we regard our calibration as conservative.

Relative risk aversion, IES, and subjective discount factor are set to replicate the low historical average of the risk-free rate and the consumption claim risk premium estimated by Lustig et al.

(2013). Replicating 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.

The parameters ν and θ_c control the labor supply and are chosen to yield a steady-state share of hours worked of 1/3 and a steady-state Frisch elasticity of 0.7, respectively. These values are standard in the literature.

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 (7), controls the markup and hence profits in the economy. We choose this parameter to match the empirical share of profits in aggregate income. The parameter η, the elasticity of new intermediate goods with respect to R&D, is within the range of the 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 of the U.S. economy over the 1929–2008 sample.

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.

4 Short-Term-Oriented Tax Smoothing and the Distribution of Risk

In panels A and B of figure 1, we depict the response of the tax rate after a positive shock to government expenditures and a negative shock to productivity, respectively. Since these responses are qualitatively the same under time-additive preferences, for brevity we plot only the responses under our benchmark calibration. According to equations (17)–(18), in both cases the government responds to these shocks by initially lowering the tax rate below the level required to achieve a zero deficit. Over the long horizon, however, the government increases taxation above average in order
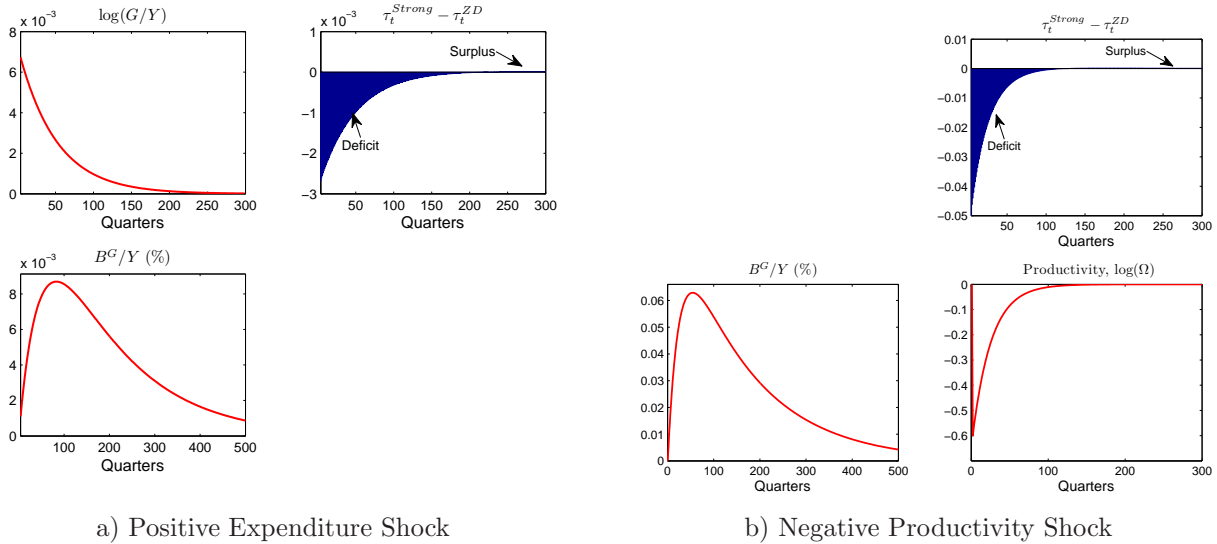
a) Positive Expenditure Shock   b) Negative Productivity Shock

Fig. 1 - 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 in table 1. The fiscal system is determined by equations (17)–(18). The zero-deficit policy is obtained by imposing $\phi_B = 0$. The countercyclical policy is obtained by setting $\rho_B^4 = .98$ and $\phi_B = .4\%$.

to run surpluses and repay debt. Good news for short-run taxation levels always comes with bad news for long-run fiscal pressure. In our stochastic environment, this consideration explains the existence of a relevant trade-off between short- and long-run risk.

In what follows, we first describe the impact of this fiscal policy on macroeconomic aggregates by looking at impulse response functions. This step helps to explain the change in the distribution of consumption risk across policies and preferences. 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. When the agent has recursive preferences, in contrast, the same policy creates significant welfare costs. Third, we relate these welfare results to the market value of patents and the term structure of profit risk. In the next section, we show that with recursive preferences welfare benefits can be obtained by means of a fiscal policy oriented toward long-term stabilization. Our welfare cost computations are reported in Appendix C.

4.1 Dynamics

Time-additive preferences. We set $\psi = 1/\gamma = 1/7$ to study the time-additive preferences case, a useful benchmark to evaluate fiscal policy implications for consumption growth. All other parameters are kept constant at their benchmark values reported in table 1.

We depict the impulse response functions of key variables of interest upon the realization of adverse expenditure and productivivity shocks in figures 2(a) and 2(b), respectively. In each sub-figure, the plots on the left-hand side refer to realized values of labor, output, and consumption growth. The right-hand side panels, in contrast, refer to the dynamics of the one-period-ahead expectation about these variables.

We note two things about figure 2. First, under our active policy the short-run response of our variables of interest is less pronounced than under the zero-deficit policy. Although almost invisible, this different dynamic behavior is important, as it guarantees that our active policy does what it is supposed to do, i.e., it promotes short-run stabilization in consumption and leisure. Second, expectations are very similar across the zero-deficit and active policy cases, implying that our active policy does not radically change long-term dynamics in a model with CRRA. This result is in sharp contrast with that of the recursive preferences case.

Recursive preferences. Similarly to the case of time-additive preferences, in figure 3 we depict the impulse response of key variables of interest with recursive preferences. The top-left panel of figure 3(a) shows that when an adverse government shock materializes, labor tends to fall, as in the CRRA case. This is due to the substitution effect: a higher level of government expenditure requires a higher tax rate, which depresses the supply of labor services. When the government implements a strong tax smoothing policy, the immediate increase in the tax rate is less severe, and for this reason labor falls less than under the zero-deficit policy. Under this calibration, the short-run stabilization effect of our simple policy is sizeable and visible.

The top-right panel of figure 3(a) shows that this short-run stabilization comes at the cost of a lower expected recovery speed. At all possible horizons, indeed, the expected growth rate of labor under the tax-smoothing policy is lower than under the zero-deficit policy. This effect is due to the
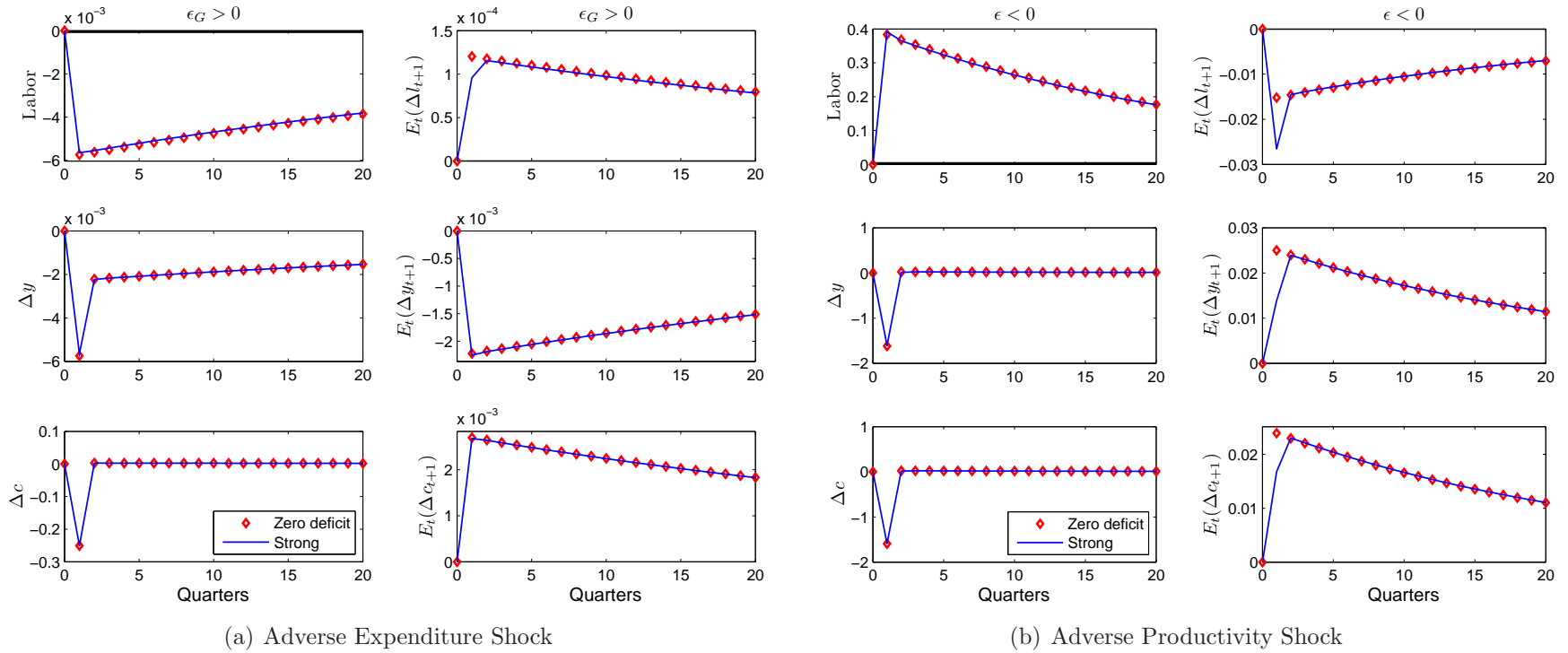
(a) Adverse Expenditure Shock

(b) Adverse Productivity Shock

Fig. 2 - Zero-deficit versus Strong Tax Smoothing: Impulse Responses in the CRRA Case

Notes - This figure shows quarterly log-deviations from the steady state. All deviations are multiplied by 100. All the parameters are calibrated to the values used in table 1, except the IES which is set to $1/\gamma = 1/7$. The fiscal system is determined by equations (17)–(18). The diamond-shaped markers refer to the zero-deficit policy ($\phi_B = 0$). The solid line is associated with a strong countercyclical fiscal policy ($\phi_B = .4\%$).
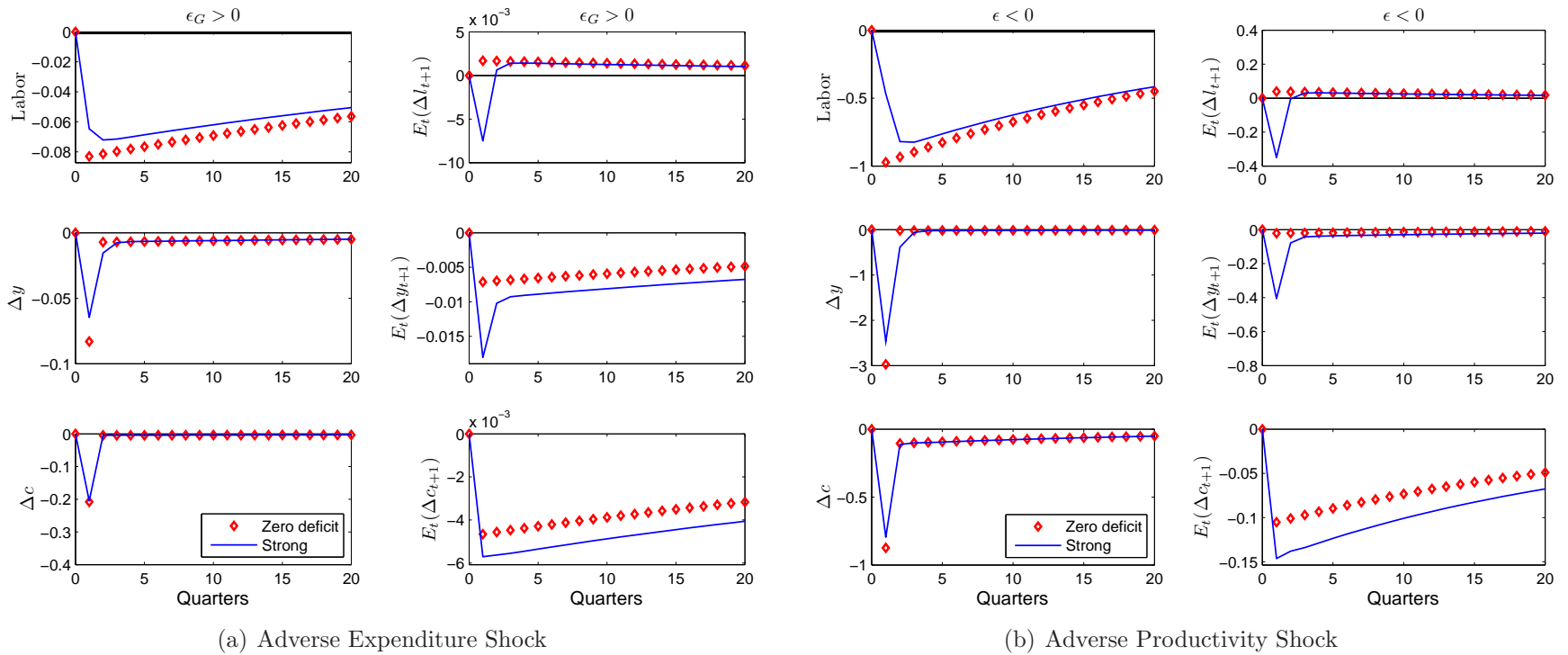
(a) Adverse Expenditure Shock

(b) Adverse Productivity Shock

Fig. 3 - Zero-deficit versus Strong Tax Smoothing: Impulse Responses in the EZ Case

Notes - This figure shows quarterly log-deviations from the steady state. All deviations are multiplied by 100. All the parameters are calibrated to the values used in table 1. The fiscal system is determined by equations (17)–(18). The diamond-shaped markers refer to the zero-deficit policy ($\phi_B = 0$). The solid line is associated with a strong countercyclical fiscal policy ($\phi_B = .4\%$).

fact that over time the government keeps taxes at a higher level in order to repay public debt. In this sense, the government is trading off short-run labor volatility for long-run labor volatility by making the effects of government expenditure shocks less severe on impact, but more long-lasting. In contrast to the case of time-additive preferences, this effect is quantitatively significant. In the next section, we show that this channel is responsible for relevant variations in both welfare and equilibrium growth.

Labor growth dynamics are relevant to the understanding of aggregate output growth adjustments over both the short- and long-run (equation (8)). The two middle panels of figure 3(a) show that under the short-term-oriented tax smoothing policy, the government is able to reduce the decrease in output growth when the shock materializes (left panel). This stabilization effect, however, comes at the cost of amplifying the reduction in expected long-run growth (right panel). Such a significant drop in output growth reflects not only labor growth dynamics, but also capital accumulation alterations. Specifically, the responses of output account for the fact that after an increase in government expenditure there are fewer resources allocated to R&D and hence a lower innovation speed, A_{t+1}/A_t, for the long-run.

What we have discussed so far is also true when the economy is subject to a negative productivity shock. As shown in figure 3(b), the tax smoothing policy is able to reduce the short-run fall in employment and output only at the cost of a slower recovery for both of these variables.

Finally, the bottom two panels of both figures 3(a) and 3(b) show that our tax smoothing policy alters consumption growth exactly as it does for output growth: a reduction in short-run consumption adjustments comes at the cost of more pronounced movements in expected future growth upon the realization of both expenditure and productivity shocks.

Crucially, in table 2 we show that this kind of tax smoothing policy tends to make expected consumption growth more persistent, i.e., it makes the impact of the exogenous shocks on consumption more long-lasting. As ϕ_B increases, the volatility of consumption, $\sigma(\Delta c)$, declines, whereas the half-life of the consumption long-run component, $E_t[\Delta c_{t+1}]$, increases. Since the long-run component of consumption is relatively small, the half-life of long-term consumption growth can increase substantially even though the persistence of consumption growth, $ACF_1(\Delta c)$, remains basically unchanged and consistent with the data. In the next section, we show that the trade-off between

Table 2 - Short-Run Tax Smoothing and Consumption Distribution

	Data	Zero-deficit $\phi_B = 0$	Weak $\phi_B = .3\%$	Strong $\phi_B = .4\%$
$\sigma(\Delta c)$	2.34	2.14	2.08	2.07
$ACF_1(\Delta c)$	0.44	0.58	0.59	0.59
Half-life $E_t(\Delta c_{t+1})$		34.62	50.99	54.23
$E(\Delta c)$	2.03	2.04	2.01	1.99

Notes - This table reports the summary statistics of our model as calibrated in Table (1). The half-life of $E_t[\Delta c_{t+1}]$ is expressed in quarters. All moments except the half-life and the autocorrelation of consumption growth, $ACF_1(\Delta c)$, are annualized and in percentages. Columns correspond to different levels of intensity of the countercyclical fiscal policy described in equations (17)–(18). The speed of debt repayment is determined by $\rho_B^4 = .98$.

short-run volatility of consumption growth and amount of long-term growth risk is responsible for the decline of average growth.

4.2   Distribution of Risk, Patent Value, and Welfare

In this section, we explore the welfare implications of our simple short-term-oriented tax smoothing policy under both time-additive and recursive preferences (figures 4 and 5, respectively). For each preference setting, we depict welfare costs as well as our measure of short- and long-run consumption risk (subfigures 4(a) and 5(a)). Since welfare depends also on average growth and the latter is a reflection of patent value (equation (22)), we additionally plot variations in both average patent value and profit risks (subfigures 4(b) and 5(b)).

Time-additive preferences.   Focusing on figure 4, we note three relevant results. First, our simple fiscal policy does what it is designed to do: it reduces short-term risk of both consumption and profits. This short-run stabilization is more pronounced when tax smoothing is more persistent (higher ρ_B) and in the case of a greater response to economic shocks (higher ϕ_B).

Second, consistent with the results obtained when studying the impulse response functions of our model, short-run stabilization does not alter in any significant way the long-run properties of consumption and profits. Hence, with time-additive preferences there is no trade-off between short- and long-run risk.
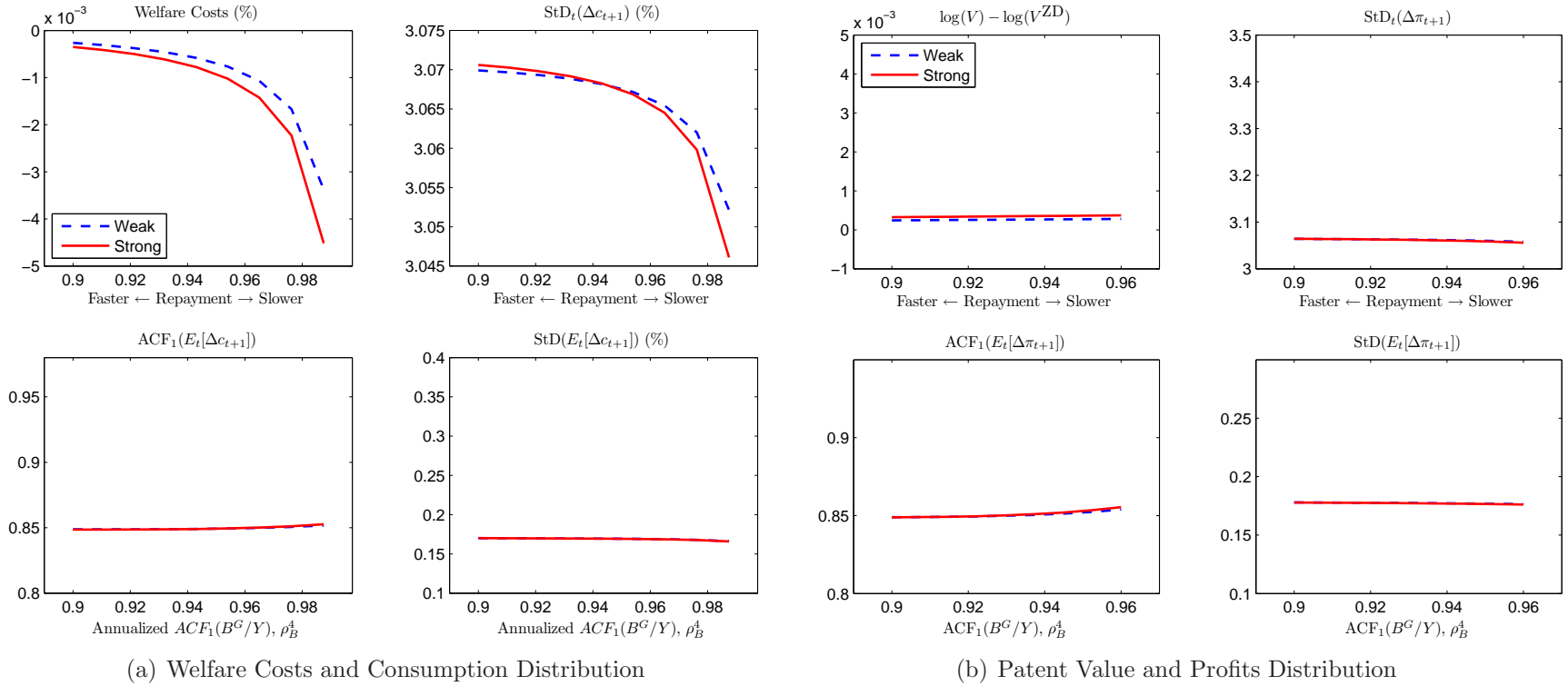
(a) Welfare Costs and Consumption Distribution

(b) Patent Value and Profits Distribution

Fig. 4 - Welfare Costs and Patent Value in the CRRA Case

Notes - Panel A of this figure shows both the welfare costs and key moments of consumption growth associated with different fiscal policies specified by equations (17)–(18). Welfare is compared to the case of a zero-deficit fiscal policy and is expressed in lifetime consumption units. Panel B shows both the average value of patents and key moments of the profits distribution. All the parameters are calibrated to the values used in table 1, except the IES, which is set to $1/\gamma = 1/7$. The lines reported in each plot are associated to different levels of intensity of the countercyclical fiscal policy. Weak and strong policies are generated by calibrating ϕ_B to .3% and .4%, respectively. The horizontal axis corresponds to different annualized autocorrelation levels, ρ_B^4, of debt-to-output ratio, B^G/Y; the higher the autocorrelation, the lower the speed of repayment.

(a) Welfare Costs and Consumption Distribution

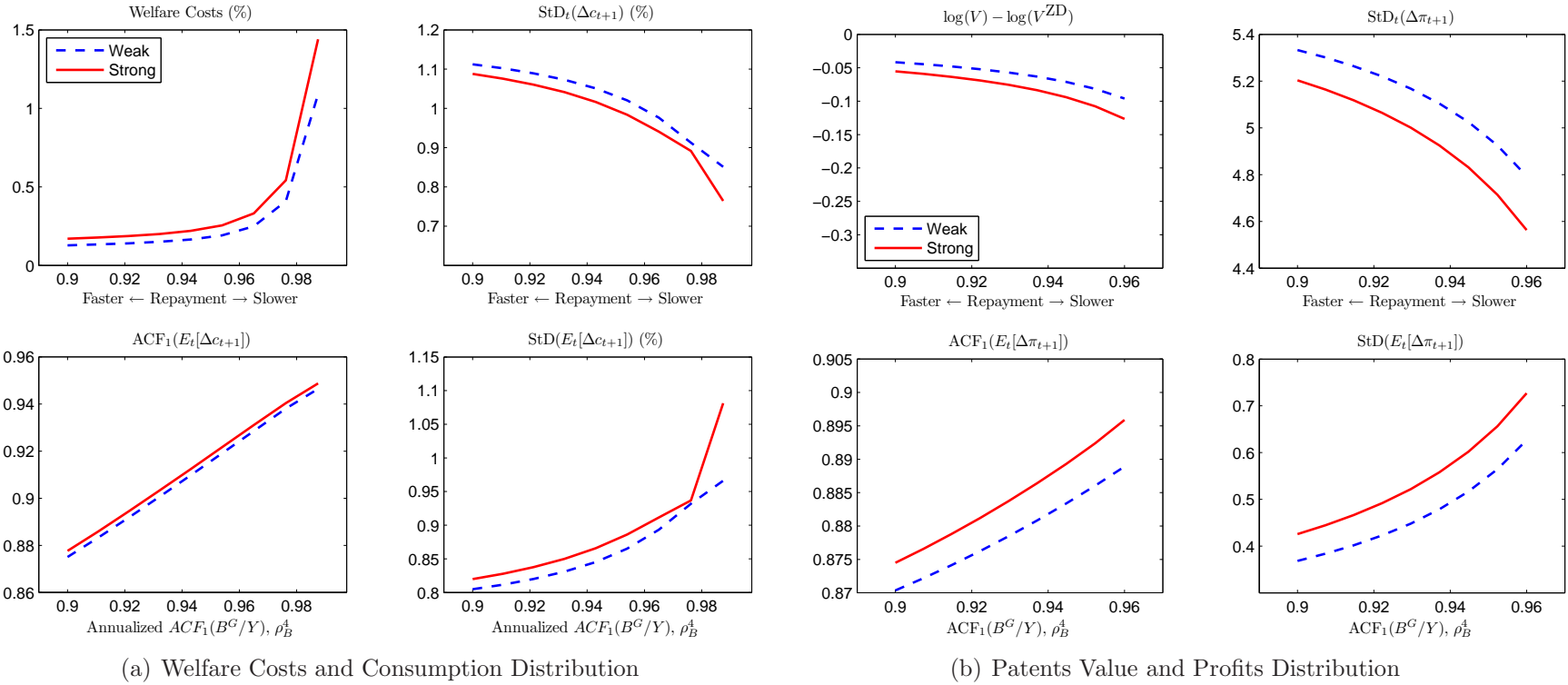(b) Patents Value and Profits Distribution

Fig. 5 - Welfare Costs and Patents' Value in the EZ Case

Notes - Panel A of this figure shows both the welfare costs and key moments of consumption growth associated with different fiscal policies specified by equations (17)–(18). Welfare is compared to the case of a zero-deficit fiscal policy and is expressed in lifetime consumption units. Panel B shows both the average value of patents and key moments of the profits distribution. All the parameters are calibrated to the values used in table 1. The lines reported in each plot are associated with different levels of intensity of the countercyclical fiscal policy. Weak and strong policies are generated by calibrating ϕ_B to .3%, and .4%, respectively. The horizontal axis corresponds to different annualized autocorrelation levels, ρ_B^4, of debt-to-output ratio, B^G/Y; the higher the autocorrelation, the lower the speed of repayment.

Third, since the representative agent is sensitive only to short-run risk, and both short-run consumption growth and profits are less risky under our active fiscal policy, the average value of patents is higher than it would be under a zero-deficit tax policy. This result implies that the unconditional growth rate of consumption is higher under this tax smoothing scheme than under a zero-deficit rule. A higher average growth rate paired with less-severe short-run consumption fluctuations produces welfare benefits, as shown in the top-left panel of figure 4.

Recursive preferences. Our results change dramatically in the setting with recursive preferences. In sharp contrast to the time-additive preferences case, our short-run-oriented fiscal policy produces welfare costs. The source of these welfare costs is twofold. First of all, consistent with our previous analysis of the dynamics of consumption growth, short-run stabilization is accompanied by an increase in long-term growth risk. Specifically, as we increase the intensity of our policy, ϕ_B, or the extent of tax smoothing, ρ_B, the conditional expected growth rate of consumption becomes more persistent and volatile (bottom two panels of figure 5(a)). The reduction of short-run fluctuations comes at the cost of more sluggish long-term consumption dynamics. Since our agent has a preference for early resolution of uncertainty, these long-lasting consumption fluctuations depress welfare.

Further, our tax policy produces the same kind of trade-offs when we look at profits. As ϕ_B and ρ_B increase, short-run profit volatility declines, but at the cost of greater long-run profit risk. With recursive preferences, this trade-off ultimately depresses the average value of patents with respect to the case of a zero-deficit policy. As a result, innovation is discouraged and long-term growth is lower than under the zero-deficit policy. Permanent growth losses paired with greater long-run consumption risk outweigh the reduction in short-run risk and produce welfare costs.

To better illustrate how our short-term-oriented tax policy affects profit risk premia across different horizons, in figure 6 we depict the variation of the whole term structure of profit excess returns across the active and zero-deficit fiscal policies. Specifically, let $P_{n,t}^{\pi,Active}$ ($P_{n,t}^{\pi,ZD}$) denote the time t value of profits realized at time $t+n$ under our active (zero-deficit) fiscal policy. The
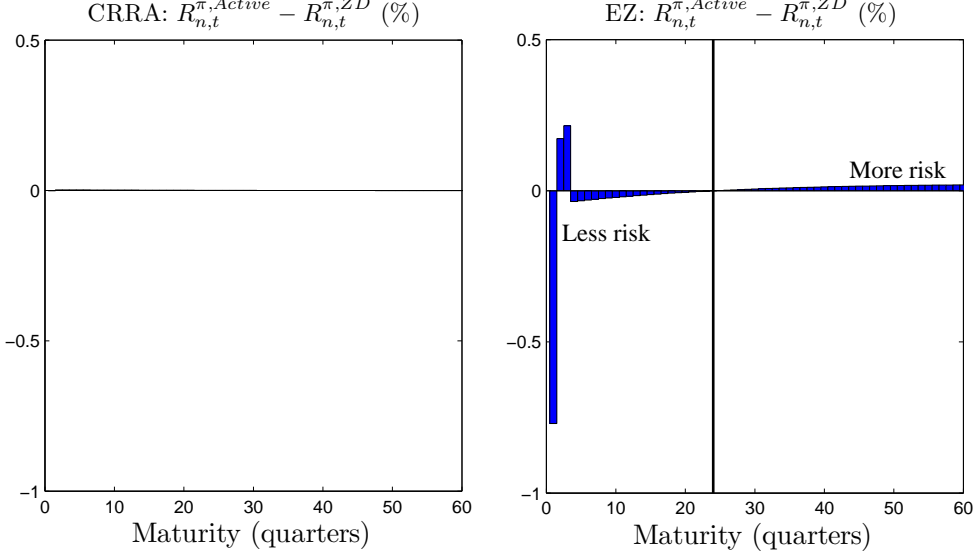
29

Fig. 6 - Fiscal Policies and Term Structure of Profits

Notes - This figure depicts the term structure of profit average excess returns under time-additive preferences (left panel) and recursive preferences (right panel). Let $P_{n,t}^{\pi,Active}$ ($P_{n,t}^{\pi,ZD}$) denote the time-t value of profits realized at time $t+n$ under our active (zero-deficit) fiscal policy. The one-period excess return of a zero-coupon claim to profits with maturity n is defined as:

$$R_{n,t}^{\pi,j} = E_t[P_{n-1,t+1}^{\pi,j}/P_{n,t}^{\pi,j}] - r_t^f, \quad j \in \{Active, ZD\}.$$

Excess returns are annualized and in percentages. All the parameters are calibrated to the values used in tables 1 and 2. In the case of CRRA preferences, we set $\psi = 1/\gamma = 1/7$. The countercyclical fiscal policy described in equations (17)–(18) is calibrated so that $\phi_B = .4\%$ and $\rho_B^4 = .97$.

one-period excess return of a zero-coupon claim to profits with maturity n is

$$R_{n,t}^{\pi,j} = E_t[P_{n-1,t+1}^{\pi,j}/P_{n,t}^{\pi,j}] - r_t^f, \quad j \in \{Active, ZD\}.$$

Under time-additive preferences, the variation in the excess returns of profits with different maturity is basically zero (left panel, figure 6). This explains why under time-additive preferences the improvement in the average value of patents is very small.

Under recursive preferences, in contrast, the fiscal system becomes a vehicle by which to significantly alter the shape of the term structure of profits. Specifically, under our benchmark calibration of the active policy, the value-weighted return of a strip of dividends paid over a maturity of up to 24 periods (6 years) is less risky than under the zero-deficit policy. This reduction of short-term risk, however, comes at the cost of greater risk over the long horizon. Since our representative agent is very patient and adverse to long-run risk, the increase in long-term risk premia compounded over

the infinite horizon dominates and depresses patent values and growth.

4.3 Utility Mean-Variance Frontier and the Role of IES

In the previous section, we argued that the implications of fiscal policies aimed at short-run stabilization depend critically on whether we adopt time-additive or recursive preferences. In this section, we show that these results are driven by the IES, a parameter about which there is still substantial uncertainty. The early macroeconomic literature (see Hall (1988), among others) suggests a value for the IES of about 0.5; recent macro-finance studies, in contrast, suggest a value as high as 2 (see,e.g., Bansal and Yaron (2004), Bansal et al. (2007), and Colacito and Croce (2011)).

To better highlight the impact of the IES on welfare, we focus on the following ordinally equivalent transformation:

$$\widetilde{U}_t = \frac{U_t^{1-1/\psi}}{1 - 1/\psi}.$$

As in Colacito and Croce (2012), we obtain the following approximation:

$$\widetilde{U}_t \approx (1 - \beta)\frac{u_t^{1-1/\psi}}{1 - 1/\psi} + \beta E_t \left[\widetilde{U}_{t+1}\right] - (\gamma - 1/\psi)Var_t \left[\widetilde{U}_{t+1}\right] \kappa_t, \tag{27}$$

where $\kappa_t \equiv \frac{\beta}{2E_t\left[U_t^{1-1/\psi}\right]} > 0$. When $\gamma = 1/\psi$, the agent is utility-risk neutral and preferences collapse to the standard time-additive case. When the agent prefers early resolution of uncertainty, i.e., $\gamma > 1/\psi$, uncertainty about continuation utility, $Var_t \left[\widetilde{U}_{t+1}\right]$, reduces welfare $E \left[\widetilde{U}_t\right]$. With recursive preferences, therefore, welfare is determined not only by short-run consumption smoothing, but also by continuation utility smoothing.

In the left panel of figure 7, we depict the utility mean-variance frontier generated by our short-run-oriented policy when the IES is set to 1.7. We plot two different lines associated with different values of the intensity parameter ϕ_B. Each line is traced by varying the persistence of debt ρ_B^4 from .9 to .96. As tax smoothing increases, long-term utility risk increases and depresses the average continuation utility, as stated in equation (27).[4] Adopting a stronger intensity, ϕ_B, makes this

---

[4]Along our frontier, in equilibrium, the expected value and volatility of continuation utility are linked through two channels. The first channel is a direct one implied by equation (27). The second channel is indirect and relates to the simultaneous reduction in the aggregate growth rate discussed in the previous section.
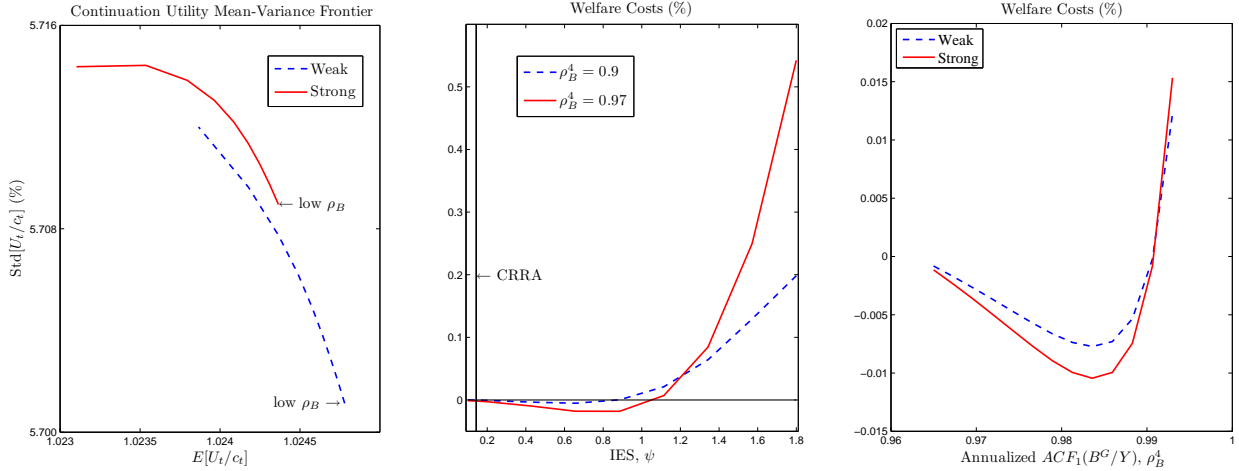
Fig. 7 - Utility Mean-Variance Frontier and the Role of IES

Notes - The left panel shows the utility mean-variance frontier (equation (27)) generated by our short-run-oriented policy (equations (17)–(18)) when we vary ϕ_B and ρ_B, and all other parameters are set to their benchmark values reported in table 1. In the middle panel, we plot welfare costs as a function of the IES. All other parameters are set to their benchmark values and $\phi_B = .4\%$. In the right panel, all parameters are calibrated as in table 1, except for the IES, which is set to unity. Weak and strong refer to setting ϕ_B to .3% and .4%, respectively.

trade-off more severe by shifting the frontier up (greater long-run utility risk) and to the left (lower average welfare). We do not report the frontier with time-additive preferences, as it essentially collapses to just a point.

In the middle panel of figure 7, we depict welfare costs as a function of the IES. All other parameters are fixed at their benchmark values. We make two observations. First, varying the IES changes the welfare results of our short-run-oriented fiscal policy both qualitatively and quantitatively. From a qualitative point of view, when the IES is smaller than one, short-run stabilization is welfare enhancing, whereas the opposite is true when the IES is set to higher values. From a quantitative point of view, our welfare cost function decreases only marginally for low values of the IES, but it rises sharply as the IES becomes greater than one. An asset-pricing-driven calibration of the IES in excess of unity, therefore, unveils a very different perspective on fiscal policy design.

Second, welfare costs are not monotonic in the IES because this parameter alters simultaneously the intertemporal smoothing attitude and the preference for early resolution of uncertainty. As the IES increases, welfare tends to increase as the effective degree of patience increases. This implies that both the risk-free rate and the average return of the patents decline, promoting more growth

and hence welfare benefits. But as the IES increases, the aversion to long-run utility risk, $\gamma - 1/\psi$, rises as well. Under our benchmark calibration, when the IES becomes greater than one, the increased amount of long-term risk produced by our active policy dominates and generates welfare losses.

In the right panel of figure 7, we examine welfare costs as a function of the fiscal parameters (ϕ_B, ρ_B) while simultaneously keeping fix the IES to unity. This is a particularly interesting experiment for at least three reasons: (i) this value stands in between those assumed in the asset pricing and macroeconomic literatures; (ii) this calibration corresponds to the log case, i.e., a benchmark in several real-business-cycle models; and (iii) the results can be interpreted in terms of fear of model misspecification, as in Hansen and Sargent (2007).

We highlight two key results. First, under this calibration, aversion to long-term risk is lower than under our benchmark calibration, and hence it plays a more moderate role. For this reason, short-term stabilization is able to produce welfare benefits even if preferences are not of the time-additive form. Second, benefits are non-monotonic with respect to speed of debt repayment, ρ_B. In particular, tax smoothing maximizes welfare benefits for $\rho_B \approx .985$. As the persistence of debt starts to exceed this value, the welfare benefits decline and eventually turn into losses, consistent with the intuition obtained under our benchmark calibration: excessive short-term-oriented tax smoothing produces welfare costs.

5 Long-Term-Oriented Tax Smoothing

So far we have focused on financing policies aimed at stabilizing short-run fluctuations, and we have seen that they are welfare-inferior to a simple zero-deficit policy. In this section we focus on a different way to approach stabilization. Specifically, we study the effects of a financing policy aimed at stabilizing future expected profit growth, consistent with equations (17) and (19). Since in our economy there is a positive link between expected profits and patent values, the government rule is now designed to stabilize the stock market, as opposed to the labor market.

In this setting, the government increases current taxation (reduces current debt) with respect to the zero-deficit case when expected profits are below average. Specifically, if profits are expected
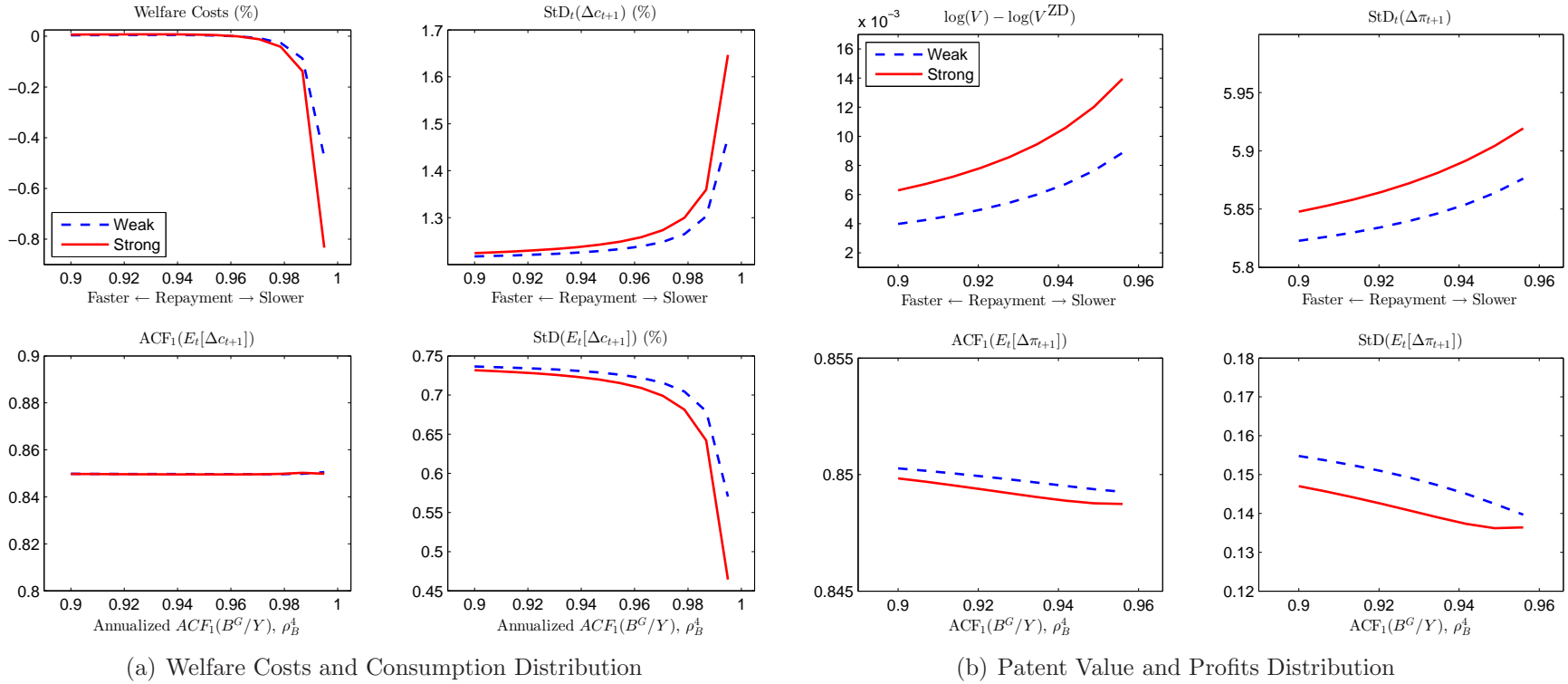
(a) Welfare Costs and Consumption Distribution

(b) Patent Value and Profits Distribution

Fig. 8 - Welfare Benefits from Long-Run Stabilization

Notes - Panel A of this figure shows both the welfare costs and key moments of consumption growth associated with different fiscal policies. Welfare is compared to the case of a zero-deficit fiscal policy and is expressed in lifetime consumption units. Panel B shows both the average value of patents and key moments of the profits distribution. All the parameters are calibrated to the values used in table 1. The lines reported in each plot are associated with different levels of intensity of the fiscal policy described in equations (17) and (19). Weak and strong policies are generated by calibrating ϕ_B to .3% and .4%, respectively. The horizontal axis corresponds to different annualized autocorrelation levels, ρ_B^4, of debt-to-output ratio, B^G/Y; the higher the autocorrelation, the lower the speed of repayment.

to grow at a rate below average, the government counterbalances these negative long-run profit expectations with lower future tax rates. In order to remain solvent, the government has to increase taxation in the short-run.

We illustrate the implications of this policy for both welfare and the distribution of consumption and profits in figure 8. In contrast to short-run stabilization, long-term stabilization produces welfare benefits. On the one hand, this policy is costly because it increases short-run volatility. On the other hand, our simple policy in equation (19) enables the government to reduce long-run risk in both consumption and profits. Since long-term stabilization enhances the market value of patents, the average growth is greater as well. Under our benchmark calibration, higher growth and lower long-term risk outweigh the increase in short-term risk and produce welfare benefits.

The relevance of this result is twofold. First, it shows that zero-deficit is not an optimal financing policy. Hence, our previous results are not driven by the fact that we have chosen an economy in which any fiscal policy is bound to produce welfare costs compared to a simple zero-deficit rule. Second, this experiment shows that the financing of public debt with a mix of taxes and deficit can be beneficial, provided that it is aimed at long-term stabilization.

6   R&D Subsidy and Expenditure Risks

Subsidy risk.   The decentralized equilibrium in our economy is far from the first-best for two reasons beyond the fact that taxation is distortionary. Specifically, average investment is below its own first-best level because (i) intermediate producers have monopoly power, and (ii) innovators do not take into account the positive externality that current innovation has on future productivity in the R&D sector (equation (12)).

In the previous section we have abstracted away from the welfare implications of fiscal policies aimed simultaneously at reducing market imperfections and stabilizing fluctuations. In this section, we consider the case in which the government offers a subsidy proportional to investment in order to bolster accumulation of technologies and growth.

Specifically, the total liability of the government includes both government expenditure and the total transfer granted to innovators, $SUB_t = \tau_t^{sub} S_t$. Given this subsidy, the free-entry condition

takes the form

$$(1 - \tau_t^{sub})\frac{1}{\vartheta_t} = E_t[M_{t+1}V_{t+1}],$$

and debt evolves as follows:

$$B_t = B_{t-1}(1 + r_t^f) + (G_t + SUB_t - T_t).$$

In this section, we consider the short-term-oriented fiscal policy described in equations (17)–(18) extending it with the following short-term-oriented subsidy policy:

$$\begin{aligned}
\tau_t^{sub} &= \frac{\exp\{\widetilde{\tau}_t^{sub}\}}{1 + \exp\{\widetilde{\tau}_t^{sub}\}} \in (0,1) \\
\widetilde{\tau}_t^{sub} &= \widetilde{\tau}_0^{sub} + \widetilde{\tau}_1^{sub}(\log L_{ss} - \log L_t),
\end{aligned} \tag{28}$$

so that the government increases subsidies when the labor market is weak and reduces them when labor is above steady state.

In figure 9, we compare welfare obtained under our active policy with subsidies and under the zero-deficit policy without subsidies ($SUB_t = 0$ and $G_t = T_t$, $\forall t$). We highlight two results. First, the introduction of subsidies creates welfare benefits, despite the fact that it requires more distortionary financing. There is hence scope for fiscal rules that improve upon the zero-deficit policy studied in section 4.

Second, subsidies can improve the level of welfare, but they do not resolve the tension between short- and long-run stabilization. As shown in figure 9, a short-term-oriented subsidy policy can reduce short-term consumption volatility, but only at the cost of substantially increasing long-term risk and depressing growth. A strong counter-cyclicality in the subsidy rate can make the subsidy-induced welfare benefits null.

Previous literature has focused almost exclusively on the determination of the optimal average subsidy rate. In contrast to previous literature, this experiment suggests that a complete study of welfare must take into consideration both short- and long-run subsidy rate uncertainty.
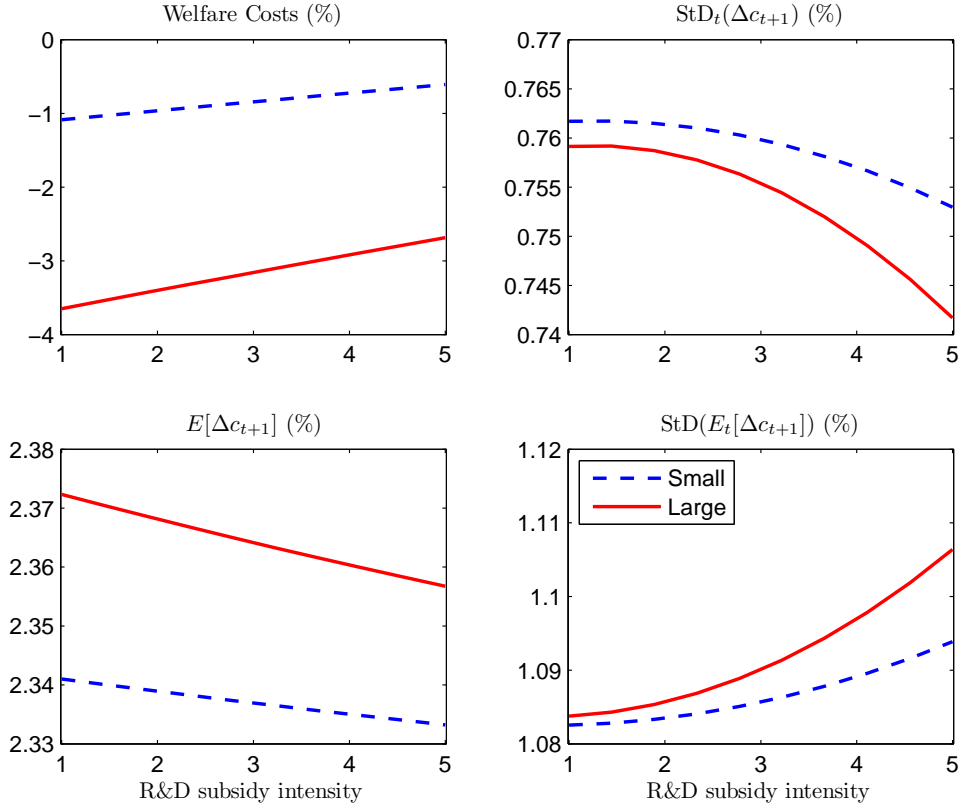
Fig. 9 - Welfare Costs with R&D Subsidy

Notes - This figure shows both the welfare costs and key moments of consumption growth associated with different fiscal policies. Welfare is compared to the case of a zero-deficit fiscal policy and is expressed in lifetime consumption units. All the parameters are calibrated to the values reported in table 1. The subsidy policy is described by equation (28). Small and large policies are generated by calibrating $\widetilde{\tau}_0^{sub}$ to .1% and .2%, respectively. The horizontal axis corresponds to different levels of R&D subsidy intensity, $\widetilde{\tau}_1^{sub}$. The financing policy is short-term-oriented, as described in equations (17)–(18). We set $\phi_B = .4\%$ and $\rho_B^4 = .99$.

Expenditure risk. An analogous statement can be made about the exogenous source of fiscal risk in our economy, i.e., government expenditure. As shown in figure 10, small increases in the volatility or the half-life of expenditure shocks can produce substantial declines in welfare regardless of the presence of a subsidy and regardless of the average size of government expenditure.

Our study is the first to highlight the strong link between different forms of fiscal risks and long-term potential growth and to show that with recursive preferences these risks play a major role. Specifically, our analysis proves that different financing schemes can substantially alter the transmission mechanism linking exogenous shocks to the distribution of consumption risk. In a model with endogenous growth and recursive preferences, long-run fiscal risks are a first-order
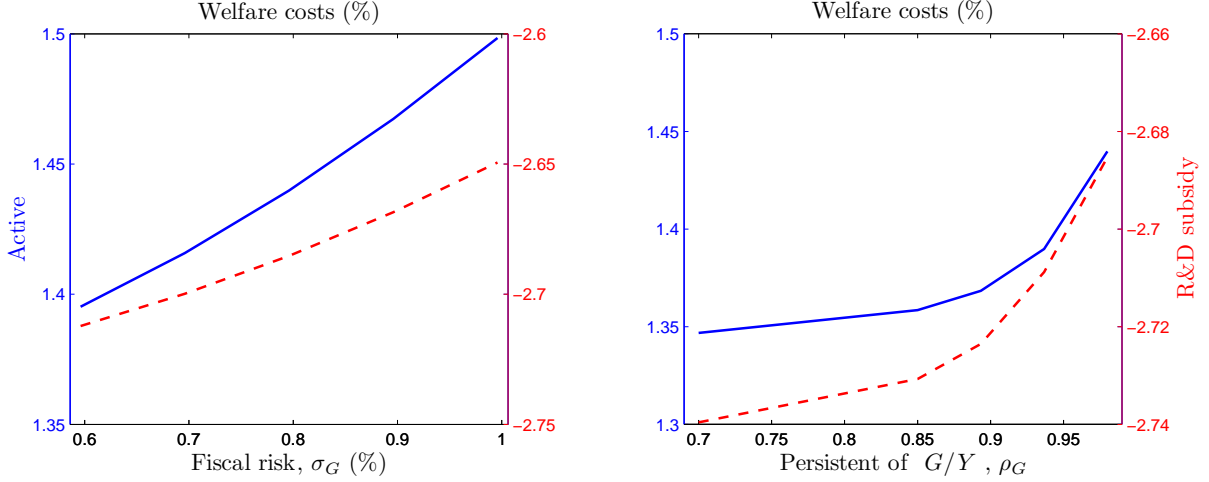
Fig. 10 - Welfare Costs and Expenditure Risks

Notes - This figure shows the welfare costs associated with different dimensions of expenditure risk. Welfare is compared to the case of a zero-deficit fiscal policy and is expressed in lifetime consumption units. All the parameters are calibrated to the values used in table 1. The lines reported in each plot are associated with different levels of fiscal risks, σ_G (left panel), and different levels of persistence of government expenditure, ρ_G (right panel). In both panels, the solid line (left scale) is associated with the short-term-oriented tax smoothing policy described in equations (17)–(18). We set $\phi_B = .4\%$ and $\rho_B^4 = .99$. The dashed line (right scale) refers to the same short-term-oriented tax smoothing policy, augment with the subsidy policy detailed in equation (28). We set $\widetilde{\tau}_0^{sub} = .2\%$ and $\widetilde{\tau}_1^{sub} = 5$.

determinant of the economy's long-term potential.

7   Conclusion

Recent fiscal interventions have raised concerns about U.S. public debt, future fiscal pressure, and long-run economic growth. This paper studied fiscal policy design in an economy in which (i) the household has recursive preferences and is averse to both short- and long-run uncertainty, and (ii) growth is endogenously sustained through innovations whose market value is sensitive to the intertemporal distribution of consumption and profit risk.

In this setting, long-term tax dynamics affect the risk-adjusted present value of future profits. By reallocating the timing of tax distortions, tax smoothing alters the intertemporal composition of growth risk and hence the incentives to innovate, thereby affecting long-term growth and welfare.

We find that countercyclical tax policies promoting short-run stabilization substantially increase long-run uncertainty, causing a costly decline in innovation incentives and growth. In contrast, tax smoothing policies aimed at stabilizing long-term growth can significantly increase growth and

welfare, even though short-run consumption risk can remain substantial.

Our analysis thus identifies a novel and significant tension between short-run stabilization and long-run growth and welfare. This tension is driven by risk considerations quantified through the lens of a general equilibrium asset pricing model with endogenous growth. Given the magnitude of our welfare results, we regard long-term fiscal risk as a first-order determinant of fiscal policy design. Since our study abstracts away from various channels through which fiscal stabilization may generate significant welfare benefits, future research should focus on the net welfare effects of fiscal intervention.

On a broader level, our analysis conveys the need to introduce risk considerations into the current fiscal policy debate. Rather than exclusively focusing on average tax pressure, fiscal authorities should be concerned with the timing and the uncertainty surrounding fiscal policy decisions.

Further research should consider the government's incentives to pursue short- versus long-run stabilization policies. Commitment, political economy incentives, and private information as in Farhi et al. (2013), and Sleet (2004), will be extremely relevant in this context.

It will be important to examine to what extent the government has incentives to resort to monetization of debt as a fiscal policy instrument (Hall and Sargent 2011). Future studies should also investigate the interaction between unemployment and growth (Chugh and Arseneau 2012). In addition, risk considerations should be included in economies with heterogeneous agents (Violante 2002) in order to link the intertemporal and cross-sectional distribution of consumption risk.

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Appendix A. Distortions versus Crowding Out

Thus far we have assumed that the government uses taxes to finance an unproductive government expenditure. This assumption, however, introduces uncertainty about both the substitution effect and the crowding-out effect, i.e., the negative income effect generated by government expenditure. In order to disentangle the crowding-out effect from the pure intertemporal redistribution of consumption risk, in this section we assume that the government uses taxes to finance a mandatory lump-sum transfer to the household, TR_t, that replaces G_t in equation (14). The consumer and government budget constraints and the resource constraint become, respectively:

$$
\begin{aligned}
C_t + Q_t Z_{t+1} + B_t &= (1 - \tau_t) W_t L_t + (Q_t + \mathcal{D}_t) Z_t + (1 + r_{f,t-1}) B_{t-1} + TR_t, \\
B_t &= (1 + r_{f,t-1}) B_{t-1} + TR_t - T_t \\
Y_t &= C_t + S_t + A_t X_t.
\end{aligned}
$$

This specification allows us to keep all marginal distortions in the first-order conditions without having to deal with the change in the allocation generated by changes in G_t.

Figure 11 confirms our previous findings: it is the persistent alteration of the tax rate that changes the long-run behavior of consumption and produces welfare costs with recursive preferences. The crowding-out effect produced by government expenditure is relevant, but it explains just a small fraction of the welfare costs that we found in the previous section.

Since U.S. entitlements are larger than public expenditure, considering a model with both transfers and expenditure would amplify both the amount of public liabilities and our welfare results.

Appendix B. Optimal Labor Taxation

In this section, we briefly summarize the determinants of optimal labor taxation in our setup. These results are based on Croce et al. (2013) and are obtained assuming access to state-contingent debt. For the sake of simplicity, we use the following monotonic transformation of our utility function:

$$
\tilde{U}_t = \tilde{u}_t + \beta (E_t \tilde{U}_{t+1}^{1-\zeta})^{\frac{1}{1-\zeta}},
$$

where $\tilde{U}_t = \frac{U_t^{1-\frac{1}{\psi}}}{1-1/\psi}$, $\tilde{u}_t = (1-\beta) \frac{u_t^{1-\frac{1}{\psi}}}{1-1/\psi}$, and $\zeta = \frac{\gamma - \frac{1}{\psi}}{1-\frac{1}{\psi}}$. For the sake of notation, in what follows we drop the $\tilde{\ }$.
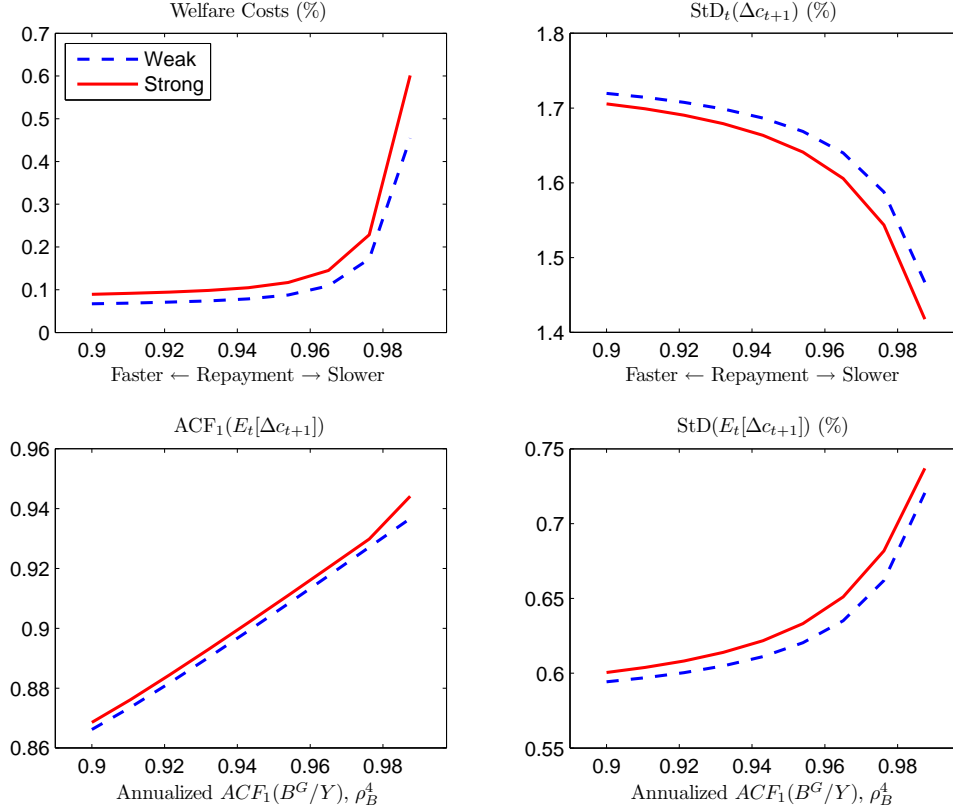
Let

$$
M_t := \Pi_{i=1}^t m_i
$$

Fig. 11 - Welfare Costs and Consumption Distribution with Transfers

Notes - This figure shows the welfare costs and key moments of consumption growth. All the parameters are calibrated to the values in table 1, except for the IES, $\psi = 1/\gamma = 1/7$. The lines reported in each plot are associated with different levels of intensity of the countercyclical fiscal policy described in equations (17)–(18). Weak and strong policies are generated by calibrating ϕ_B to .3% and .4%, respectively. The horizontal axis corresponds to different annualized autocorrelation levels, ρ_B^4, of debt-to-output ratio, B^G/Y; the higher the autocorrelation, the lower the speed of repayment. Welfare costs are calculated as in Appendix C. In this figure, we assume taxes are used to finance a lump-sum transfer to the representative consumer.

be a martingale with increment

$$m_{t+1} := \frac{U_{t+1}^{1-\zeta}}{E_t U_{t+1}^{1-\zeta}},$$

where we normalize $M_0 = m_0 = 1$. Given these definitions, the stochastic discount factor in our model can be written as

$$\Lambda_{t+1} = \beta m_{t+1}^{\frac{\zeta}{\zeta-1}} \frac{u_{ct+1}}{u_{ct}}.$$

Finally, define

$$
\begin{aligned}
\Omega(C, l) &= \Omega(C, 1-L) \\
&= u_c(C, 1-L)C - U_l(C, 1-L)L.
\end{aligned}
$$

45

The time-zero Ramsey problem consists in maximizing the household's lifetime utility subject to the following constraints, with multipliers reported in parentheses:

$$(\Phi) \qquad E_0 \sum_{t=0}^{\infty} \beta^t M_t^{\frac{\zeta}{\zeta-1}} \left[\Omega(C_t, 1 - L_t) - u_{ct} \left(A_t \left(\frac{1}{\alpha} - 1 \right) X_t - S_t \right) \right] = u_{c0} B_0 \qquad \text{(B.1)}$$

$$(\beta^t \pi_t \lambda_t) \qquad G_t + C_t + A_t X_t + S_t = Y_t \qquad \text{(B.2)}$$

$$(\beta^t \pi_t \mu_t) \qquad A_{t+1} = \vartheta_t S_t + (1 - \delta) A_t \qquad \text{(B.3)}$$

$$(\beta^t \pi_t \rho_t) \qquad \frac{1}{\vartheta_t} = E_t \beta m_{t+1}^{\frac{\zeta}{\zeta-1}} \frac{u_{ct+1}}{u_{ct}} V_{t+1} \qquad \text{(B.4)}$$

$$(\beta^{t+1} \pi_{t+1} \nu_{t+1}) \qquad M_{t+1} = \frac{U_{t+1}^{1-\zeta}}{E_t U_{t+1}^{1-\zeta}} M_t \qquad \text{(B.5)}$$

$$(\beta^t \pi_t \xi_t) \qquad U_t = u_t + \beta (E_t U_{t+1}^{1-\zeta})^{\frac{1}{1-\zeta}}. \qquad \text{(B.6)}$$

The implementability constraint (B.1) and the resource constraints (B.2) are standard, as they are present even in the simple setup of Lucas and Stokey (1983). Our problem, however, has to take into account also the physical accumulation of varieties (B.3) and the free-entry condition (B.4) prescribed by the Romer model. Furthermore, since we adopt recursive preferences, we need to keep track of both the martingale (B.5) and the future utility (B.6) evolution.

Given these constraints, the shadow-value of consumption from a Ramsey perspective, λ_t, is

$$\lambda_t = \lambda_t^{LS} \cdot \underbrace{M_t^{\frac{\zeta}{\zeta-1}} + u_{ct} \xi_t - M_t^{\frac{\zeta}{\zeta-1}}}_{\text{Intertemporal Distorsion Channel}} \cdot u_{cc,t} \Phi \underbrace{(\rho_t - \rho_{t-1} \vartheta_{t-1} V_t - D_t)}_{\text{Asset Price Channel}}, \qquad \text{(B.7)}$$

where $\lambda_t^{LS} := u_{ct} + \Phi \Omega_{c,t}$ is the shadow value of consumption in the Lucas and Stokey (1983) economy, $D_t := A_t \Pi_t - S_t$ are the aggregate dividends, and ξ_t evolves as a martingale with respect to $\pi_t M_t$ with $\xi_0 = 0$ and $\text{StD}_t[\xi_{t+1}] \propto \zeta$.

With time-additive preferences, $\zeta = 0 \to \xi_t = 0$, and $M_t^{\frac{\zeta}{\zeta-1}} = 1$. With exogenous endowment growth, $\rho_t = 0$ and $D_t = 0$, as investment and profits vanish. Without endogenous growth and recursive preferences, our multiplier corresponds to that found by Lucas and Stokey (1983). Equation (B.7), therefore, enables us to disentangle two important channels. First, with innovation-driven growth, the tax system can alter the growth of the economy by affecting the private valuation of patents, V_t. In this setup, risk and asset prices become important determinants of tax systems (the asset price channel).

Second, in contrast to the time-additive preferences case, our Ramsey planner must consider the entire intertemporal distribution of risk. This intertemporal dimension relates to the martingales ξ_t and M_t. These forward-looking elements imply that the entire intertemporal distribution of future tax distortions becomes a determinant of the optimal tax system (the intertemporal distortions

channel). Croce et al. (2013) provide sufficient conditions for the existence of an equilibrium but do not characterize the dynamics of ξ_t and M_t. We study the role of long-run tax distortions through simple and implementable tax rules.

Appendix C. 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 the 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++`.