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The fiscal arithmetic of a slowdown in trend growth[☆]

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ABSTRACT

We study the fiscal policy implications of a slowdown in trend growth using an estimated stochastic growth model. Our analysis underscores the risks associated with fiscal rules linked to growth rates, which may prove unsustainable under permanent shifts in productivity growth. For equilibria to exist, fiscal policy must respond to the slowdown ensuring that the government budget constraint holds in the low growth regime. While the slowdown imposes significant welfare costs on households, it also triggers a substantial endogenous response that boosts capital accumulation and functions as an automatic stabilizer. If fiscal policy maintains the provision of public goods per capita constant, the slowdown gives rise to a pleasant fiscal arithmetic, requiring tax cuts or a higher target debt-to-output ratio for long-term fiscal sustainability. We discuss the ramifications of various fiscal strategies, including increasing per capita public spending, altering the tax structure, and adjusting the target debt-to-output ratio.

1. Introduction

It appears that over the past two decades or so, the growth rate of output per capita in advanced economies has slowed down. This slower pace, reflected not just in output but also in weak growth rates of investment, consumption, real wages, and productivity, has led to downward revisions in growth forecasts by policymakers and professional forecasters.[1]

As Fig. 1 shows, the recent slowdown has been felt not only in the United States but also in many advanced small open economies such as Australia, Canada, New Zealand, Norway, Sweden and the United Kingdom. Against this background, we study what the implications of a global slowdown – a slowdown at home and abroad – are for a fiscal authority in a small open economy. We do so with an estimated stochastic growth model of the Australian economy, but as Fig. 1 shows, our findings will be of interest more broadly.[2]

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[1] In its 2015 World Economic Outlook report, the International Monetary Fund had projected potential growth in advanced economies to average 1.6 percent per year over the period 2015–2020, which was significantly lower than the average of 2.25 percent during the period 2001–2007 (IMF, 2015). More recently and even after taking into account the pandemic-induced fluctuations, the IMF's baseline projection indicates a continuation of the global growth deceleration pre-pandemic, with growth rates having decreased from 3.5 percent in 2022 to 3.0 percent in 2023, and an anticipated further decrease to 2.9 percent in 2024, all of which remain lower than the historical average of 3.8 percent during the period 2000–2018 (IMF, 2023).

[2] One can observe similar patterns of slowing growth for consumption and for investment. See the online appendix for these additional figures. Our online appendix can be found at https://sites.google.com/site/marianokulish/home/research.

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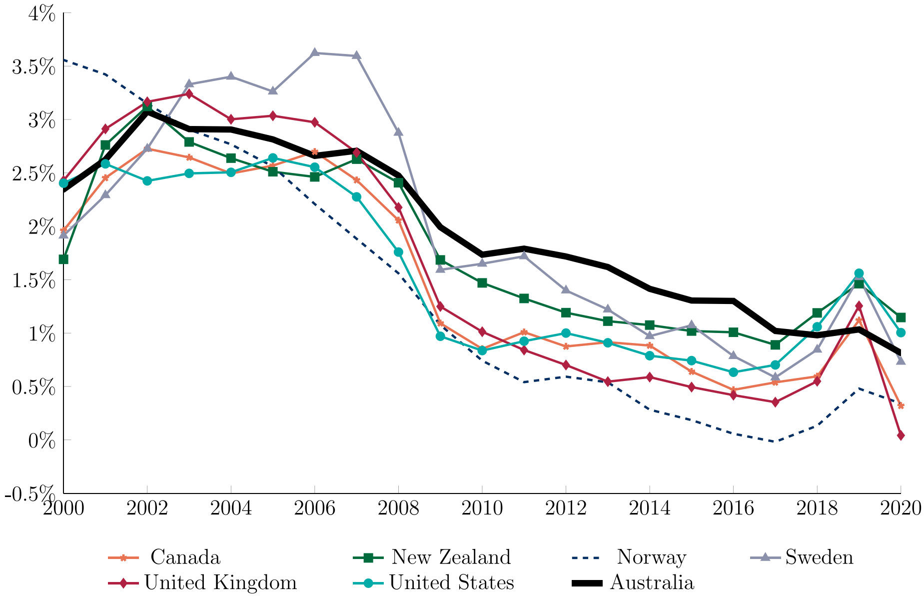

Fig. 1. Average GDP per capita growth % per year. Note: The GDP per capita growth is computed as a rolling average over the past 10 years. *Source:* Authors' calculations; FRED.

Australia provides a compelling case. This is because, in spite of the fact that to date – abstracting from the COVID 19 recession – the Australian economy has experienced the longest economic expansion on record,[3] Australia's economic performance since the mid 2000s has deteriorated: output per capita grew on average at 1 per cent per year over the past decade, compared to almost 2.5 per cent per year on average prior to the mid 2000s (Fig. 1). This is despite Australia having had a relatively strong performance during the Global Financial Crisis suggesting financial frictions were not as prevalent as in the United States. Furthermore, despite an extraordinary boost in the terms of trade, per capita output growth remained lower during the mining boom of 2003–2014 than during the mid 1980s and 1990s, a time when commodity prices were relatively flat. Although the deterioration of 2014–2016 in Australia's terms of trade is likely to have contributed to weaker growth outcomes, the low-frequency movements in the data suggest that the slowdown in trend growth goes beyond higher frequency fluctuations in the terms of trade.[4]

Our work is connected to three strands of the literature. One strand assesses empirically the slowdown in U.S. trend growth: Antolin-Diaz et al. (2016) use a dynamic factor model to document a decline in U.S. trend growth; McCririck and Rees (2016) use a business cycle model that abstracts from fiscal policy and find breaks in productivity growth; and Eo and Morley (2020) using a Markov-switching statistical model, detect a reduction in trend growth that began in 2006. Another strand revisits the secular stagnation hypothesis of Hansen (1939): prominent examples are Summers (2015) who argues in support of a demand-side interpretation while Cowen (2011) and Gordon (2015) emphasise lower productivity growth as the cause of the recent slowdown; Jones (2023) shows that an ageing population gives rise to a transition with persistently lower productivity growth and studies the implications for monetary policy of a lower real interest rate and a more frequently binding zero lower bound; Eggertsson and Mehrotra (2014) propose an illustrative open economy model to show that a secular stagnation triggered by an oversupply of savings can be eliminated by fiscal stimulus in an open economy. Another strand of the literature, Straub and Coenen (2005), Forni et al. (2009), Leeper et al. (2010) and Ratto et al. (2009), estimates fiscal policy rules to measure the effects of fiscal policy with fully specified structural models.

This paper is different. Although our analysis finds evidence of a slowdown across various specifications, our main goal is not to establish the existence or magnitude of such a slowdown. Instead, our main contribution is to take the possibility of a slowdown in trend growth seriously in order to understand what the quantitative implications for fiscal policy could be. In our model, a permanent slowdown shifts the balanced growth path of the economy. This structural change not only places the economy on a transition towards a new balanced growth path but also confronts the fiscal authority with the need to adapt to a new low growth environment. As we discuss below, whether this new long run exists, what its characteristics are and what the transition may be, depend crucially on the way the fiscal regime responds. To study these questions we use a variant of the canonical open economy stochastic growth model that we extend to include a fiscal authority that levies taxes on labour income, capital income, consumption expenditures as well as lump-sum taxes, in order to fund interest and principal payments on accumulated government

[3] See https://www.economist.com/leaders/2018/10/27/what-the-world-can-learn-from-australia.

[4] It is worth noting that the productivity slowdown observed in measures of total factor productivity started around 2003–2004. See 5260.0.55.002 — Estimates of Industry Multifactor Productivity at this link.

debt and government expenditures. The cause of a permanent slowdown in our model is a permanent fall in the growth rate of labour-augmenting technology, consistent with a growth accounting exercise which shows that the bulk of the slowdown can be attributed to slowing total factor productivity.[5]

The estimated model is used to quantify and analyse how the slowdown could affect the economy and its fiscal position. The estimates suggest that in response to the slowdown, the long-run government budget constraint adjusts through the following permanent changes of the fiscal rules: a fall of the government spending to output ratio, a reduction of the tax rate on labour income and an increase of the tax rate on capital income. In Section 6, we use the estimated model to discuss other plausible fiscal financing scenarios and what their associated counterfactual implications would be.

A priori, one may think that a slowdown in trend growth will necessarily deteriorate the fiscal position. This would be the case if government expenditures were to keep growing at the old faster rate but tax revenues were to grow at the new slower rate. Then an ever-growing fiscal imbalance would lead to unsustainable debt dynamics. The model makes clear that unsustainable debt dynamics are inconsistent with a stable equilibrium. In fact, an important message of our paper is that fiscal rules cast in growth rates are dangerous as they can suddenly become inconsistent with the existence of a stable equilibrium in the presence of regime changes in trend growth.

The slowdown raises the more general issue of understanding the economy's response in the context of changing policies as well as the ability of a given fiscal regime to withstand structural changes in the economy. That fiscal policy rules can evolve over time is clear from the discussion of Pappa (2021) for Europe. Our analysis studies how fiscal rules may adapt to a slowing growth regime and shows how the market response to the slowdown operates as an important automatic stabilizer. A crucial aspect of the government spending response depends on whether fiscal policy aims to maintain a constant government spending to output ratio or a certain level of government spending per capita. If the government keeps the provision of public goods per capita constant, then the slowdown implies a fall in the government spending to output ratio, which implies that the fiscal balance can be restored with either a fall in the tax revenues to output ratio or an increase of the target debt to output ratio. Initially, the slowdown reduces consumption as households lower their estimate of permanent income. But it also increases investment, which is partly funded by foreign savings chasing higher relative returns. As consumption falls, so do consumption tax revenues deteriorating the primary deficit and increasing the government debt to output ratio. The increase in capital accumulation eventually increases tax bases and helps restore the fiscal balance in the long-run. Thus an important message of this paper is that the endogenous response of the private sector to the slowdown increases tax bases, giving rise to a pleasant fiscal arithmetic: restoring fiscal balance requires tax cuts or increasing the government spending to output ratio or increasing the target debt to output ratio or some combination of these. A pleasant fiscal arithmetic does not mean, however, that the slowdown improves welfare. As we show below, the slowdown imposes significant welfare costs on households.

In estimation we use the method of Kulish and Pagan (2017) to allow, but not to impose, a break in the growth rate of labour-augmenting productivity. This method is also used by Kulish and Rees (2017) to estimate changes in the long-run level of the terms of trade, by Jones (2023) to estimate a model undergoing a demographic transition, and by Gao et al. (2020) to estimate changes in the inflation target. Similar to Aguiar and Gopinath (2007) who use consumption and net exports to identify the contributions of permanent and transitory shocks to the *level of productivity*, we use aggregate data but to identify transitory from permanent changes to the *growth rate of productivity*. Permanent shocks to productivity have a permanent effect on the level of output, but only a transitory effect on the growth rate of output. Our baseline model has permanent shocks to the level of productivity but allows for a break in its growth rate.[6] Like these papers, we rely on many observables to achieve identification: real GDP per capita growth, real private consumption per capita growth, net exports to GDP, government spending to GDP, a measure of the domestic real interest rate, a measure of the foreign real interest rate, real wage growth, government debt to GDP, consumption tax revenue to GDP, labour income tax revenue to GDP and capital income tax revenue to GDP.

We estimate the permanent change in trend growth together with the model's structural and fiscal policy rule parameters. We find that trend growth in output per capita started to fall around 2005 from just over 2 per cent towards our current estimate of just over 0.9 per cent per year. We estimate a range of different specifications of the model as well as a single equation unobserved components model on the GDP per capita series alone and find broadly similar estimates of the slowdown.

The rest of the paper is organised as follows. In Section 2 we start by developing intuition with the standard neoclassical model to understand the economic forces that are triggered when trend growth permanently falls. We then discuss two assumptions regarding the fiscal policy response to the slowdown: in one case the government fixes the provision of public goods per capita; in the other case the government fixes government spending as a proportion of GDP. The model we take to the data is described in Section 3. Section 4 presents the estimates. Section 5 evaluates the estimated model. Section 6 uses the estimated model to study counterfactual responses of fiscal policy to the slowdown and evaluates its welfare implications. Section 7 performs robustness checks. Section 8 concludes and proposes avenues for further research.

[5] See the online appendix for details about the growth accounting exercise.

[6] The online appendix shows that a version of the model with transitory shocks to the level of technology implies similar estimates of the slowdown and of the transitional dynamics.

2. The slowdown in a neoclassical economy

It is useful to build intuition for the quantitative exercise that follows by first considering a slowdown in trend growth in the textbook closed economy Ramsey–Cass–Koopmans model (Ramsey, 1928; Cass, 1965; Koopmans, 1963). The continuous time neoclassical growth model is well-known, so we restrict our attention to those equations needed to convey the key intuition.[7] As we discuss below, the main result in the closed economy case carries over to the open economy case as well.

Output is produced according to $Y = K^{\alpha}(ZL)^{1-\alpha}$, where Z captures labour augmenting technology which grows at the rate $z = \dot{Z}/Z$, K is the capital stock and L is labour taken to be inelastically supplied and normalised to unity. Lower case letters denote variables in units of effective labour. The representative household preferences expressed in consumption per effective labour are given by:

$$U = \int_0^{\infty} e^{-(\rho-(1-\sigma)z)t} u(c) dt$$

where ρ is the subjective discount rate. Assuming $u(c) = \frac{c^{1-\sigma}-1}{1-\sigma}$, the equilibrium yields paths for consumption and the capital stock that solve the system of differential equations below.[8]

$$\frac{\dot{c}}{c} = \frac{1}{\sigma}\left[\alpha k^{\alpha-1} - \rho - \delta - \sigma z\right] \tag{1}$$

$$\dot{k} = k^{\alpha} - (z+\delta)k - c \tag{2}$$

Along the balanced growth path, $\dot{c} = \dot{k} = 0$, and consumption and capital are given by:

$$\bar{k} = \left(\frac{\alpha}{\rho+\delta+\sigma z}\right)^{\frac{1}{1-\alpha}} \tag{3}$$

$$\bar{c} = \bar{k}^{\alpha} - (z+\delta)\bar{k} \tag{4}$$

A slowdown in trend growth corresponds to a reduction in the growth rate of labour-augmenting technology, that is, a fall in z. The fall in trend growth results in a permanently higher steady-state level of capital, as implied by Eq. (3). In other words, $\frac{\partial \bar{k}}{\partial z} < 0$. Using Eq. (3) in (4) it may be shown that if $\rho > (1-\sigma)z$, then

$$\frac{\partial \bar{c}}{\partial z} = [\rho - (1-\sigma)z]\frac{\partial \bar{k}}{\partial z} - \bar{k} = \frac{[-\sigma(\rho-(1-\sigma)z) - (1-\alpha)(\rho+\delta+\sigma z)]}{(1-\alpha)(\rho+\delta+\sigma z)} k < 0$$

and so consumption per unit of effective labour also increases in the long-run following a fall in trend growth.

Fig. 2 shows transitional dynamics in the $k-c$ plane. The economy is initially on its balanced growth path represented by point A. The fall in trend growth shifts the $\dot{c} = 0$ locus to the right and the $\dot{k} = 0$ locus upwards. When trend growth declines, consumption falls to point E putting the economy on its new stable saddle path. Thereafter, c and k rise gradually towards their new steady-state values represented by point B.

As variables are shown in units of effective labour, their evolution does not coincide with the evolution of the levels. Once on the new balanced growth path, point B, the levels of consumption and capital grow at a slower rate even though consumption and capital per unit of effective labour are now higher. This is analogous to what is obtained in the Solow model in response to a fall in the growth rate of the population; slower population growth implies that the levels eventually grow at a slower rate even though per capita quantities are higher in the new balanced growth path.

The fall in trend growth gives rise to income and substitution effects. The fall in z lowers permanent income as real wages are expected to grow at a slower rate. As a result, consumption on impact falls. The fall in consumption increases saving which adds to the capital stock. But the fall in z implies a substitution effect through its impact on the real interest rate, the rate of return on capital net of depreciation. In steady state, Eq. (1) implies that the rate of return on capital net of depreciation, $r = f'(k) - \delta$, equals the household's discount rate adjusted by trend growth, $\rho + \sigma z$. On impact, however, the fall in z may be thought to act as an increase in the real interest rate, as it implies that the net rate of return on capital is above the rate implied by the household's effective discount factor, that is $f'(k) - \delta > \rho + \sigma z$, giving households the incentive to increase saving. As capital accumulates in the transition, its marginal product, $f'(k)$, gradually falls bringing the real interest rate, r, back in line with $\rho + \sigma z$. In the new balanced growth, the capital per unit of effective labour is higher as is output and consumption per unit of effective labour, but the levels, of course, grow at a slower rate.

The slowdown in trend growth gives rise to an endogenous response which favours the accumulation of inputs, in this case, of capital. As we will show below when we introduce fiscal policy, this endogenous accumulation of capital in response to the slowdown acts as an automatic stabilizer because it increases the tax base.

Next, we introduce a government sector that spends on goods and services and levies lump-sum taxes. The government maintains a balanced budget so

$$g = \tau \tag{5}$$

[7] See Acemoglu (2008) for a comprehensive discussion of the neoclassical growth model.

[8] For the household's problem to have a well-defined solution it must be that $\rho > (1-\sigma)z$.

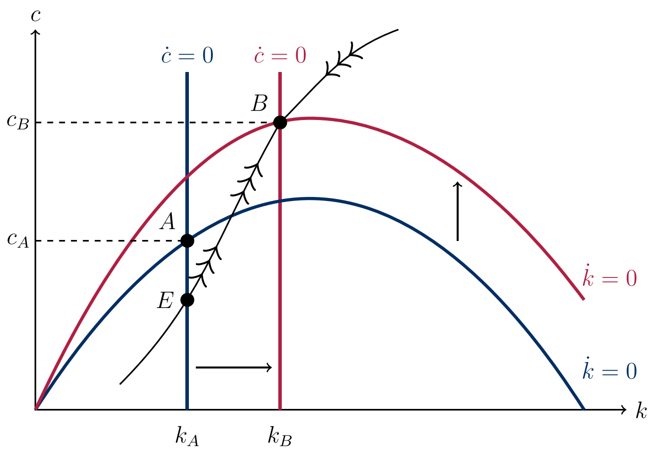

Fig. 2. Fall in trend growth in the neoclassical model.

where g is government spending and τ are lump-sum taxes both expressed in terms of effective labour units. The equilibrium with fiscal policy yields the paths for consumption and the capital stock that solve Eq. (1) and the modified version of Eq. (2) shown below:

$$\dot{k} = k^{\alpha} - (z + \delta)k - c - g \tag{6}$$

Along the balanced growth path, the steady-state capital per unit of effective labour continues to be $\bar{k}$ as per Eq. (3). Output is therefore the same as in the case without fiscal policy, but consumption is crowded out as households must pay taxes to finance government consumption.

A fall in z leads to similar responses as before: it increases $\bar{k}$ and $\bar{y} = f(\bar{k})$. However, the impact on consumption depends on how fiscal policy responds to the slowdown. Consider the following two cases. The first, assumes government spending is set so that in steady state the government spending to output ratio is fixed at some level, say γ, that is

$$g = \gamma \bar{y} \tag{7}$$

In this case the slowdown in trend growth leads to an endogenous increase in $\bar{k}$ and $\bar{y}$ and implies an increase in g. The slowdown acts as an automatic stabilizer as it increases the tax base, $\tau = \gamma \bar{y}$.

The second case assumes the government maintains some fixed level of government spending per effective worker, so that

$$g = \tilde{g} \tag{8}$$

A fall in z increases $\bar{k}$ and $\bar{y} = f(\bar{k})$ by the same amount in both cases. But when the government follows Eq. (7), the fall in z leads to an increase in g so that the size of government in the final steady state stays at γ. In the transition, the size of government would exceed γ because Eq. (7) implies that g increases as the new steady state is known, although the economy takes time to get there. In the second case, when the government follows Eq. (8), the fall in z increases $\bar{y}$ as before but has no impact on g which stays at $\tilde{g}$. In this case the size of government permanently shrinks below γ following the fall in trend growth. but the provision of public goods per unit of effective labour remains the same.

Fig. 3 compares the transitional dynamics following a fall in z when the government follows Eq. (7), so the g/y ratio remains constant across steady states, with those obtained when the government follows Eq. (8), the case when government spending per effective worker stays constant across steady states. In the initial steady state, at point A, we set $\tilde{g}$ so that it equals $\gamma \bar{y}$. This explains why the two $\dot{k} = 0$ curves pass through point A. When z falls, consumption falls in both cases following the intuition above. But consumption falls by less when the government follows Eq. (8) reflecting that relatively less taxes are required as the size of government shrinks in the transition towards the new steady state. In the new steady state, of course, the consumption to output ratio is higher under Eq. (8) than under Eq. (7).

To extend this analysis to an open economy, one must specify if the slowdown in trend growth is solely a domestic phenomenon or a global one instead. This assumption is important because it has implications for the dynamics of real interest rate differentials between the domestic economy and the rest of the world and consequently for the evolution of net foreign assets and the trade balance. Because the data strongly suggests that the slowdown is global (Fig. 1), we consider the case in which there is a common rate of trend growth at home and abroad. As trend growth declines permanently, consumption falls as in the closed economy case and domestic and foreign real interest rates eventually converge to a common lower level although a real interest rate spread arises temporarily in the transition.

The textbook model is useful to see how a slowdown in trend growth requires some fiscal response. The government budget constraint equates spending with taxes, $g = \tau$, so in this simple model a choice about spending automatically implies a choice about taxes and vice versa. The next section sets up a more realistic model with a richer specification for fiscal policy. With government

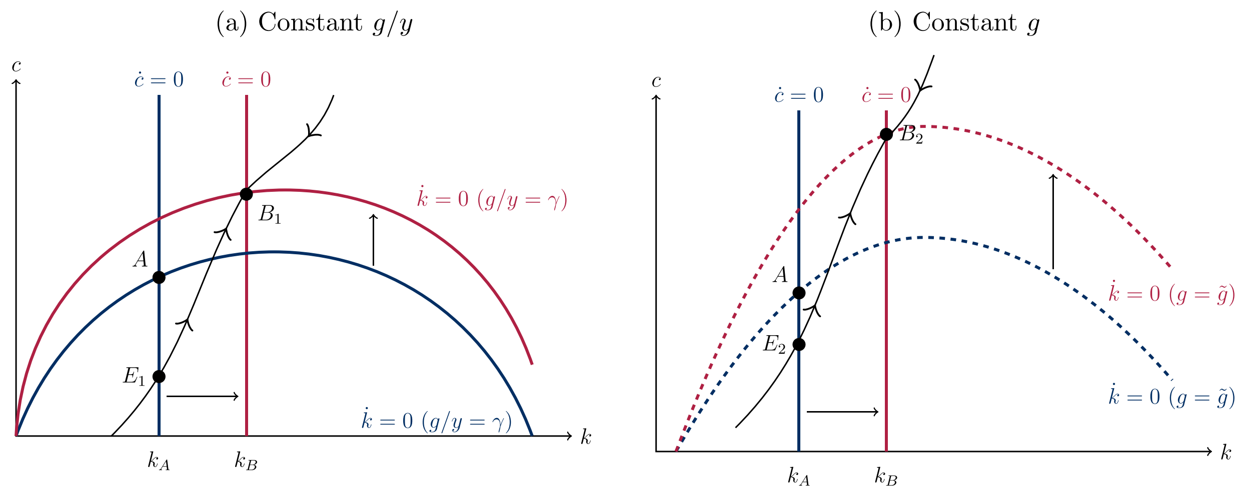

Fig. 3. Fall in trend growth with fiscal policy.

debt as well as taxes on consumption, labour and capital income, there is a richer menu of options available for fiscal reform in response to the slowdown. Conditional on spending decisions, the government will be able to satisfy the budget constraint in many ways, either by changing the target for government debt or by adjusting some or all taxes, or a combination of both. As we discuss in detail below, the way the government responds to the slowdown is crucial to determine transitional dynamics and the long-run properties of the economy.

3. A stochastic growth open economy model

Next, we set up a small open economy stochastic growth model along the lines of Uribe and Schmitt-Grohé (2017) for the empirical application that follows.

3.1. Households and firms

The representative household maximises expected lifetime utility given by:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \zeta_t \left(\log\left(C_t - hC_{t-1}\right) - \zeta_t^L \frac{L_t^{1+\nu}}{1+\nu} \right) \tag{9}$$

subject to the period budget constraint:

$$(1+\tau_{c,t})C_t + I_t + P_t^B B_t + B_t^F \leq (1+\kappa^B P_t^B)B_{t-1} + R_{t-1}^F B_{t-1}^F + (1-\tau_{w,t})W_t L_t + (1-\tau_{K,t})r_t^K K_{t-1} + TR_t$$

and the capital accumulation equation:

$$K_t = (1-\delta) K_{t-1} + \zeta_t^I \left[1 - \Upsilon\left(\frac{I_t}{I_{t-1}}\right)\right] I_t \tag{10}$$

In the equations above, C_t is consumption, $\tau_{c,t}$ is the tax rate on consumption, I_t is investment, B_t stands for long-term government bonds, P_t^B is the price of government bonds and the parameter κ^B, as in Woodford (2001), determines the maturity of government debt,[9] B_t^F stands for foreign bonds and R_t^F for its gross rate of return, L_t are hours worked, W_t is the real wage per hour worked and $\tau_{w,t}$ is the tax rate on labour income. The capital stock available for production at time t is K_{t-1} and r_t^K is its rental rate, while $\tau_{K,t}$ is the tax rate on capital income. TR_t stands for lump sum taxes or transfers. The parameter $h \in [0,1]$ is the habit formation coefficient and $1/\nu$ is the Frisch elasticity of labour supply. ζ_t is an intertemporal preference shock that follows:

$$\log \zeta_t = \rho_\zeta \log \zeta_{t-1} + \varepsilon_{\zeta,t} \tag{11}$$

and ζ_t^L is a labour supply shock that follows:

$$\log \zeta_t^L = \rho_L \log \zeta_{t-1}^L + \varepsilon_{L,t} \tag{12}$$

[9] With $\kappa^B = 0$ the specification collapses to the standard short-term one-period bond.

ζ_t^I is a shock to the marginal efficiency of investment which is assumed to follow:

$$\log \zeta_t^I = \rho_I \log \zeta_{t-1}^I + \varepsilon_{I,t} \tag{13}$$

The function that governs the investment adjustment cost satisfies, $\Upsilon(z) = \Upsilon'(z) = 0$ and $\Upsilon'' > 0$.

Output is produced with a Cobb–Douglas production function by competitive firms hiring capital and labour:

$$Y_t = K_{t-1}^{\alpha} \left(Z_t L_t\right)^{1-\alpha} \tag{14}$$

where Z_t is labour-augmenting technology whose growth rate, $z_t = Z_t / Z_{t-1}$, follows:

$$\log z_t = (1-\rho_z)\log z + \rho_z \log z_{t-1} + \varepsilon_{z,t} \tag{15}$$

and so z governs the growth rate of labour-augmenting TFP along the balanced growth path. In estimation we allow, but do not require, a break in z at some point in the sample from z to $z' = z + \Delta z$. Trend growth in the initial regime, z, is calibrated and Δz estimated. While the change in long-run productivity growth is discrete, notice that productivity growth, $\log z_t$, adjusts gradually towards its new lower long-run productivity growth, $\log z'$, governed by ρ_z, a parameter which we estimate.

The real interest rate on domestic government debt is $R_t = (1 + \kappa^B P_{t+1}^B)/P_t^B$. In steady state it can be shown that the real interest rate is related to productivity growth by the expression below

$$R = \frac{z}{\beta}$$

and the price of long-term debt in steady state would be $P^B = (z/\beta - \kappa^B)^{-1}$, which shows that valuation effect on government debt of a slowdown would be stronger the longer the maturity of government debt.

3.2. Trade balance and net foreign assets

Following Schmitt-Grohe and Uribe (2003), the interest rate that the household receives on foreign bonds depends on the economy's net foreign asset position according to the debt-elastic interest rule:

$$R_t^F = R_t^* \exp\left[-\psi_b\left(\frac{b_t^F}{y_t} - \frac{b^F}{y}\right) + \zeta_t^b\right] \tag{16}$$

where $\frac{b^F}{y}$ is the steady-state ratio of net foreign assets to output, and ζ_t^b is the country risk premium shock which follows the process below:

$$\zeta_t^b = (1-\rho_b)\zeta^b + \rho_b \zeta_{t-1}^b + \varepsilon_{b,t} \tag{17}$$

and R_t^* is the foreign real interest rate which follows the exogenous process below:

$$\log R_t^* = (1-\rho_{R^*})\log R^* + \rho_{R^*} \log R_{t-1}^* + \varepsilon_{R^*,t} \tag{18}$$

Following Garcia-Cicco et al. (2010), we allow the parameter ψ_b, governing the debt elasticity of the country premium, to be estimated rather than calibrated. Thus, the role of the country premium is not only limited to inducing stationarity, but can potentially act as a reduced form of a financial friction, influencing the model's response to aggregate disturbances.

In steady state, the foreign real interest rate is $R^* = z\exp(-\zeta_b)/\beta$. The assumption that the slowdown is global is reflected by the fact that when trend growth falls so will R^*. However, R_t^* will converge gradually, governed by ρ_{R^*}, to its lower steady state. Eq. (16) shows that if R_t^F were to exactly track R_t^* then net foreign assets would stay constant. If, however, due to endogenous persistence arising from investment adjustment costs and habits in consumption, R_t^F takes longer to reach its steady state, then the domestic real interest rate would temporarily exceed the foreign real interest rate. A positive real interest rate differential leads to a capital inflow from the rest of the world, a trade deficit and a deterioration in the net foreign asset position. Eventually the trade deficit would recover and restore the steady-state net foreign asset position, b^F/y.

The trade balance is output less domestic absorption, that is,

$$NX_t = Y_t - C_t - I_t - G_t \tag{19}$$

and the current account is therefore given by $CA_t = NX_t + (R_{t-1}^F - 1)B_{t-1}^F$, so in equilibrium, net foreign assets evolve according to:

$$B_t^F = R_{t-1}^F B_{t-1}^F + NX_t \tag{20}$$

The levels of variables, except for hours worked and interest rates, trend at the rate of z. When normalised by Z_t, however, the variables $b_t = B_t/Z_t$, $c_t = C_t/Z_t$, $y_t = Y_t/Z_t$, and so on, converge in the absence of shocks, to their steady state values which we denote by b, c, y and so on.

3.3. The government

The government receives tax payments on consumption, $\tau_{c,t}C_t$, labour income, $\tau_{w,t}W_tL_t$, and capital income, $\tau_{K,t}r_t^K K_{t-1}$, as well as lump-sum taxes, TR_t, and borrows domestically, $P_t^B B_t$, to finance government spending, G_t and make payments on outstanding debt, $(1+\kappa^B P_t^B)B_{t-1}$. Thus, the government budget constraint is:

$$P_t^B B_t + \tau_{c,t}C_t + \tau_{w,t}W_tL_t + \tau_{K,t}r_t^K K_{t-1} + TR_t = (1+\kappa^B P_t^B)B_{t-1} + G_t \tag{21}$$

We assume the government sets government spending and tax rates following fiscal rules which include a response to deviations of the government debt to output ratio $by_t = p_t^B B_t/Y_t$ from its steady state $by \equiv p^B b/y$. In particular, we assume AR(2) rules of the form[10]:

$$\log g_t = (1-\rho_g^1-\rho_g^2)\log g + \rho_g^1 \log g_{t-1} + \rho_g^2 \log g_{t-2} - (1-\rho_g^1-\rho_g^2)\gamma_{gb}\left(by_{t-1}-by\right) + \varepsilon_{g,t} \tag{22}$$

$$\tau_{c,t} = (1-\rho_c^1-\rho_c^2)\tau_c + \rho_c^1\tau_{c,t-1} + \rho_c^2\tau_{c,t-2} + (1-\rho_c^1-\rho_c^2)\gamma_{cb}\left(by_{t-1}-by\right) + \varepsilon_{c,t} \tag{23}$$

$$\tau_{w,t} = (1-\rho_w^1-\rho_w^2)\tau_w + \rho_w^1\tau_{w,t-1} + \rho_w^2\tau_{w,t-2} + (1-\rho_w^1-\rho_w^2)\gamma_{wb}\left(by_{t-1}-by\right) + \varepsilon_{w,t} \tag{24}$$

$$\tau_{K,t} = (1-\rho_K^1-\rho_K^2)\tau_K + \rho_K^1\tau_{K,t-1} + \rho_K^2\tau_{K,t-2} + (1-\rho_K^1-\rho_K^2)\gamma_{Kb}\left(by_{t-1}-by\right) + \varepsilon_{K,t} \tag{25}$$

$$\tau_t = (1-\rho_\tau^1-\rho_\tau^2)\tau + \rho_\tau^1\tau_{t-1} + +\rho_\tau^2\tau_{t-2} + (1-\rho_\tau^1-\rho_\tau^2)\gamma_{\tau b}\left(by_{t-1}-by\right) + \varepsilon_{\tau,t} \tag{26}$$

where the normalised variables $\tau_t = \frac{TR_t}{Z_t}$ and $g_t = \frac{G_t}{Z_t}$, have steady states τ and g, respectively.

In steady state, the government budget constraint, Eq. (21), expressed in terms of ratios to output, is given by:

$$\frac{g}{y} + \left(\frac{1}{\beta}-1\right)\frac{p^B b}{y} = \tau_c\frac{c}{y} + \tau_w(1-\alpha) + \tau_K\alpha + \frac{\tau}{y} \tag{27}$$

where we have used the fact that for our production function the labour share of income is $1-\alpha$ and the capital share of income is α. Eq. (27) must hold for any balanced growth path, for any value of z.

In the presence of changes in z, the way in which Eq. (27) is satisfied implies certain permanent changes to the fiscal policy rules, Eqs. (22)–(26). For example, if the government keeps g constant and by constant, then those parameters remain unchanged in those equations. Our baseline specification keeps g constant and, as we discussed above, a fall in z increases y and therefore reduces the g/y ratio in this case. Because Eq. (27) must hold along the balanced growth path, the fall in g/y implies that the right-hand side of the equation must adjust as well. In estimation, we allow for changes in τ_w and τ_K consistent with changes in fiscal policy in the mid 2000s as we explain below. In particular, we estimate the parameters $\Delta\tau_w$ and $\Delta\tau_K$ which determine the size of the changes in those tax rates and, given the estimates, lump-sum taxes, τ, adjust so the government budget constraint holds in the new steady state.[11] The baseline also assumes a constant debt to output ratio, as it is clear that policy makers in Australia are strongly averse to persistent deficits and rising debt.[12] We also take τ_c as a constant, as there were no changes to the GST after the mid 2000s when a break in growth is detected. This, however, does not imply a constant $\tau_c c/y$, as the slowdown increases c/y.

4. Empirical strategy

The method of Kulish and Pagan (2017) is used to solve and estimate the model of Section 3 in the presence of structural breaks.

The structural parameters can be categorised as either having only an impact on the dynamics of the model – persistence parameters of shock processes, adjustment costs, fiscal policy rule response parameters and standard deviations – or as having, in addition to an impact on the dynamics, an impact on the steady state. Our strategy follows that of Adolfson et al. (2007) and Kulish and Rees (2017) in that we calibrate the parameters that pin down the steady state to match first moments of an initial sub-sample of data and estimate the first category of parameters together with the consumption habit parameter h and the risk premium sensitivity ψ_b.

4.1. Calibration

We set z to 1.0055 in the initial steady state to match GDP per capita growth for the period 1983:Q1 to 2008:Q4. In the final steady state the growth rate is $z' = 1.0055 + \Delta z$, where Δz is estimated.[13] Given z, we calibrate β to 0.995 such that, in the initial steady state, the mean of the domestic real interest rate is 4.2 per cent in annual terms. We set the country risk premium, ζ_b, to match the differential between the sample means of the domestic and the foreign real interest rates. The production function parameter,

[10] In an preliminary specification we estimated AR(1) rules for the fiscal policy instruments. A marginal likelihood comparison, however, suggests AR(2) rules fit the data better.

[11] The online appendix contains results from a model where we set $\Delta\tau_w$ and $\Delta\tau_K$ to zero and so lump-sum taxes fully absorb the adjustment in the steady state government spending to output ratio g/y. That specification is allowed for and nested by the baseline specification.

[12] See, for example, David Gruen's speech in December 2009 about Australia's fiscal responses (https://treasury.gov.au/speech/the-return-of-fiscal-policy) and Treasurer Chalmers' budget speech in May 2024 (https://ministers.treasury.gov.au/ministers/jim-chalmers-2022/speeches/budget-speech-2024-25).

[13] Section G.5 of the online appendix conducts Bai–Perron tests allowing for multiple breaks. Those results suggest a single break in the series, so we take that case to be our baseline specification.

Table 1
Calibrated parameters.

Parameter	Description	Value
β	Household discount factor	0.995
δ	Capital depreciation rate	0.016
ν	Inverse Frisch	2
z	Steady-state TFP growth	1.0055
α	Capital share in production	0.29
b^*	Steady-state net foreign assets	0
g/y	Steady-state government spending to output	0.236
$p^B b/y$	Steady-state debt to output	0.536
κ^B	Term to maturity of government bonds	0.969
τ_c	Steady-state consumption tax rate	0.067
τ_w	Steady-state labour income tax rate	0.178
τ_K	Steady-state capital income tax rate	0.139
ζ_b	Country risk premium	0.0049

Table 2
Steady state calibration.

Target	Average 1983–2008	Model
Macro aggregates (annual per cent)		
Per capita output growth	2.2	2.2
Domestic real interest rate	4.2	4.2
Foreign real interest rate	2.3	2.3
Expenditure (per cent of GDP)		
Consumption	57.2	56.1
Investment	20.4	20.3
Government spending	23.6	23.6
Net exports	−1.3	0.0
Tax revenues (per cent of GDP)		
Consumption tax	3.7	3.7
Labour income tax	12.3	12.3
Capital income tax	4.1	4.1
Borrowing (per cent of annual GDP)		
Government debt	13.4	13.4

Note: Model ratios are calculated at initial regime where $z = 1.0055$.

α, is set to match the mean of the investment and consumption to output ratios. The rate of capital depreciation, δ, is set to match the consumption of fixed capital out of the net capital stock. The government debt to annual GDP ratio is set to match its sample mean of 13.4 per cent. The parameter κ^B is calibrated to match the weighted average term to maturity of Australian government bonds. The average maturity of bonds on issue is around 7 years as documented in Australia's Budget 2023–2024 Debt Statement.[14] We set the tax rates on consumption, labour income and capital income so as to match tax revenues from each source as a per cent of GDP. In the final steady state, the tax rate on labour income is $\tau'_w = \tau_w + \Delta\tau_w$ and the tax rate on capital income is $\tau'_K = \tau_K + \Delta\tau_K$, where $\Delta\tau_w$ and $\Delta\tau_K$ are estimated. The government spending to output ratio is chosen to correspond to total government spending (consumption plus investment) in the data.[15] Finally, we set the inverse Frisch elasticity of labour supply, ν, to 2, which is standard in the literature. Table 1 summarises the values of the calibrated parameters.

Table 2 evaluates the resulting calibration by comparing model moments with those in the data for the 1983–2008 subsample. We choose to match the moments in the sub-sample because in the presence of possible breaks in trend growth, full sample statistics do not reflect any one regime. The calibrated model captures key features of the economy well. There is a small discrepancy in matching net exports, but this is a deliberate choice. In steady state, Eq. (20) implies that positive net exports cover interest payments on foreign liabilities, or that interest income on foreign assets fund negative net exports. An issue arises because over our sample period the economy has had a trade deficit and a negative net foreign asset position. Because of this reason we decide to strike a balance and set the net foreign asset position to zero in steady state, which implies balanced trade.

[14] See Australia's Budget 2023–2024 Debt Statement here https://archive.budget.gov.au/2023-24/.

[15] Our choice of observable variables uses the sum of government consumption plus investment to make the model consistent with observed GDP in the data. We leave for future research assessing the implications of government investment along the lines, for example, proposed by Bouakez et al. (2017).

4.2. Estimation

We follow the approach in the literature on estimated dynamic stochastic general equilibrium models.[16] Our case, however, is non-standard because we allow for structural change and therefore jointly estimate two sets of distinct parameters: the structural parameters of the model, θ, that have continuous support and the dates of structural changes, $\mathbf{T} = (T_z, T_\sigma)$ that have discrete support; T_z is the date break in the growth rate of labour-augmenting technology[17] and T_σ is the date break in the variance of shocks. To capture the great moderation, the fact that the variance of macroeconomic aggregates has fallen, we use a parsimonious specification and introduce the parameter μ, which multiplies all standard deviations before T_σ, i.e. the standard deviations of all variables are assumed to shift in the same proportion. Both μ and T_σ are then estimated.

The joint posterior density of θ and $\mathbf{T}$ is:

$$P(\theta, \mathbf{T}|\mathbf{Y}) \propto \mathbf{L}(\mathbf{Y}|\theta, \mathbf{T})p(\theta, \mathbf{T}), \tag{28}$$

where, $\mathbf{Y} \equiv \{y_t^{obs}\}_{t=1}^T$ is the data and y_t^{obs} is a $n^{obs} \times 1$ vector of observable variables. The likelihood is given by $\mathbf{L}(\mathbf{Y}|\theta, \mathbf{T})$. The prior of the structural parameters and the prior of date breaks are taken to be independent, so that $p(\theta, \mathbf{T}) = p(\theta)p(\mathbf{T})$. We use a flat prior for $\mathbf{T}$ over admissible dates and use trimming so that the earliest possible date for the final regime (low trend growth and variances) is the first quarter of 2002. The trimming ensures that the initial regime (high trend growth and variances) is long enough and avoids incorrectly capturing a break in the early 2000's that may be due to the introduction of the goods and services tax rather than due to a change in trend growth. Kulish and Pagan (2017) discuss how to construct $\mathbf{L}(\mathbf{Y}|\theta, \mathbf{T})$ in models with forward-looking expectations and structural changes as well as how to set up the posterior sampler.

The model is estimated on 10 domestic and 1 foreign quarterly macroeconomic time series for the period 1983:Q1 to 2018:Q1. Real GDP and private consumption are seasonally adjusted and measured in chain volume terms, while government spending[18] and net exports are seasonally adjusted and measured in current prices as these enter as shares of nominal GDP. Output and consumption are expressed in per capita terms by dividing by the population derived from the GDP per capita series. These series enter in first differences. The sample mean of consumption growth is adjusted prior to estimation and the sample mean of net exports to GDP is removed to align it with the model's steady state. The hourly wage series is derived by dividing the compensation of employees series by the hours worked index. We then deflate the hourly wage by the consumption deflator. The real wage series enters in first differences with its sample mean adjusted to equal the mean of output growth. The domestic interest rate is the 90-day bank bill rate and the foreign interest rate is the U.S. 3-months treasury bill rate. The domestic and foreign nominal interest rates are converted to real rates using the trimmed mean inflation and the US core PCE inflation series, respectively.

The measure of government debt is government securities on issue expressed as a share of nominal GDP. For the tax revenues, we use sales taxes plus goods and services taxes as a measure of consumption tax revenues, the tax on individual income series as a measure of labour income tax revenues, and income tax on resident corporations and on non-residents series as a measure of capital income tax revenues. The tax revenues series are expressed as a share of nominal GDP. We adjust the mean of the consumption tax revenues to GDP series for the subsample 1983–2000 to account for the introduction of the goods and services tax in 2000.

4.3. Priors

For Δz which corresponds to the parameter of most interest in this analysis, we choose a uniform prior with a wide support of -0.01 to 0.01. This implies that the estimate for the growth rate in the final regime, z', can range anywhere between 0.9955 and 1.0155, which in annual growth rate terms translates to a range of -1.8% to 6.2%.

During the early 2000s, fiscal policy imposed a more comprehensive corporate income tax base with the main changes including imposing tax on previously exempt activities such as gold-mining and on foreign source income, a reduction of accelerated depreciation for investment in plant and equipment, as well as reducing tax concessions on superannuation. Furthermore, as pointed out by Ge (2023), over the period 2007–2010, a personal income tax reform plan was implemented which involved a series of personal income tax cuts. Such tax reforms change the effective tax rates and hence would be captured in our model by an increase in τ_K and a decrease in τ_w. For these reasons, we set uniform priors for the change in the labour income tax rate, $\Delta\tau_w$, and for the change in the capital income tax rate, $\Delta\tau_K$, with supports of [−0.08, 0] and [0, 0.08] respectively. This implies that the labour income tax rate can vary anywhere from remaining unchanged at 12.3% to decreasing to 4.3%, while the capital income tax rate can remain the same at 4.1% or increase to any value up to 12.1%.

Other choices follow the literature: Beta distributions for the persistence coefficients and Inverse Gamma distributions for the standard deviations of the shocks. We set a normal prior centred at 0.1 with a standard deviation of 1 for the debt elasticity of the country premium parameter ψ_b. For the fiscal policy rules response coefficients to the debt to output ratio, we use uniform priors over a range that restricts the coefficients so that each fiscal instrument responds to stabilise debt. This does not imply stability over the prior parameter space; it only shrinks the region of unstable debt dynamics.

[16] See An and Schorfheide (2007) for a description of standard techniques. See Kulish and Pagan (2017) for the general methodology of solving and estimating models under structural change and the online appendix for the application to the particular case we implement.

[17] We run Bai–Perron tests for structural change on the growth rate of real GDP per capita which suggest one break in the series. We therefore postulate one break in productivity growth in our sample. See the online appendix for details of this exercise.

[18] Our measure of government spending from the national accounts differs from the measure of government spending in the Commonwealth budget papers due to differences in accounting methodologies. The main difference is that government spending reported in the budget papers includes transfer payments, while our quarterly measure from the national accounts corresponds to a measure of public final demand and therefore excludes transfer payments. In our model, net transfers (lump-sum payments less lump-sum receipts) would show up in τ_t which we use as a residual to satisfy the government budget constraint Eq. (21).

Table 3
Prior and posterior distribution of the structural parameters.

Parameter	Prior distribution			Posterior distribution			
	Distribution	Mean	S.d.	Mean	Mode	5%	95%
Structural parameters							
h	Beta	0.5	0.25	0.58	0.57	0.51	0.64
Υ''	Normal	5.0	2.0	2.62	2.45	1.51	3.99
ψ_b	Normal	0.1	1.0	0.53	0.50	0.37	0.74
Δz	Uniform	[−0.01, 0.01]		−0.0030	−0.0032	−0.0047	−0.0010
$\Delta\tau_w$	Uniform	[−0.08, 0.0]		−0.0179	−0.0201	−0.0284	−0.0047
$\Delta\tau_K$	Uniform	[0.0, 0.08]		0.0474	0.0485	0.0158	0.0759
μ	Uniform	[0, 3]		1.91	1.89	1.68	2.16
Fiscal rules parameters							
γ_{gb}	Uniform	[0, 0.5]		0.166	0.026	0.013	0.418
γ_{cb}	Uniform	[0, 0.5]		0.120	0.029	0.013	0.380
γ_{wb}	Uniform	[0, 0.5]		0.037	0.021	0.007	0.091
γ_{Kb}	Uniform	[0, 0.5]		0.124	0.032	0.009	0.374
$\gamma_{\tau b}$	Uniform	[0, 0.5]		0.064	0.053	0.010	0.131
ρ_g^1	Beta	0.71	0.16	0.64	0.65	0.53	0.75
ρ_c^1	Beta	0.71	0.16	0.68	0.70	0.56	0.79
ρ_w^1	Beta	0.71	0.16	0.49	0.49	0.37	0.61
ρ_K^1	Beta	0.71	0.16	0.66	0.67	0.55	0.77
ρ_τ^1	Beta	0.50	0.19	0.21	0.19	0.09	0.34
ρ_g^2	Beta	0.71	0.16	0.31	0.31	0.20	0.42
ρ_c^2	Beta	0.71	0.16	0.30	0.29	0.19	0.41
ρ_w^2	Beta	0.71	0.16	0.36	0.36	0.25	0.47
ρ_K^2	Beta	0.71	0.16	0.29	0.28	0.18	0.40
ρ_τ^2	Beta	0.50	0.19	0.17	0.16	0.07	0.29
Other AR coefficients							
ρ_z	Beta	0.50	0.19	0.16	0.15	0.07	0.25
ρ_{R^*}	Beta	0.71	0.16	0.87	0.87	0.81	0.92
ρ_ζ	Beta	0.71	0.16	0.91	0.92	0.83	0.96
ρ_L	Beta	0.71	0.16	0.99	0.99	0.98	1.00
ρ_I	Beta	0.50	0.19	0.38	0.40	0.25	0.50
ρ_b	Beta	0.50	0.19	0.60	0.60	0.48	0.71
Standard deviations							
σ_z	Inv. Gamma	0.01	0.30	0.009	0.009	0.008	0.010
σ_{R^*}	Inv. Gamma	0.01	0.30	0.002	0.002	0.002	0.002
σ_ζ	Inv. Gamma	0.10	0.30	0.022	0.019	0.016	0.030
σ_L	Inv. Gamma	0.10	0.30	0.030	0.029	0.026	0.033
σ_I	Inv. Gamma	0.10	0.30	0.109	0.108	0.065	0.163
σ_b	Inv. Gamma	0.10	0.30	0.003	0.003	0.003	0.003
σ_g	Inv. Gamma	0.10	0.30	0.023	0.023	0.021	0.026
σ_c	Inv. Gamma	0.01	0.30	0.002	0.002	0.001	0.002
σ_w	Inv. Gamma	0.01	0.30	0.006	0.006	0.006	0.007
σ_K	Inv. Gamma	0.01	0.30	0.010	0.010	0.009	0.011
σ_τ	Inv. Gamma	0.10	0.30	0.067	0.066	0.059	0.074
Date breaks							
T_z	[2002:Q1, 2008:Q1]			2004:Q4	2005:Q1	2002:Q2	2007:Q2
T_σ	[2002:Q1, 2008:Q1]			2003:Q3	2003:Q3	2002:Q3	2003:Q4
Log marginal likelihood: −5651.5							

4.4. Structural parameters and date breaks

The estimates of the structural parameters are shown in Table 3. Starting with our parameter of most interest, Δz, there is strong evidence in favour of a slowdown in trend growth. After the break, trend growth in GDP per capita in annual terms is estimated to be around 0.93% at the mode of the posterior. And while there is some uncertainty around this estimate, there is little mass close to 2.2%, the trend growth rate of the initial regime.

The mean for the break in trend growth is estimated to be the fourth quarter of 2004 while the mode is the first quarter of 2005. There is about a 60% probability that the break in trend growth occurred between 2003 and 2005; the remaining 40% probability is spread between 2005 and 2008. This is consistent with the finding in Eo and Morley (2020) for the U.S. who estimate the break to have taken place prior to the global financial crisis of 2008/09.

The estimates also favour a significant decrease in the labour income tax rate of 2.0 percentage points at the mode of the posterior distribution. Similarly, there is strong evidence that the capital income tax rate increased by 4.8 percentage points at the mode. The absence of mass close to zero in the posterior distributions of the tax rate changes, $\Delta\tau_w$ and $\Delta\tau_K$, suggests that this specification which allows for changes in labour income and capital income tax rates provides a better fit to the data.

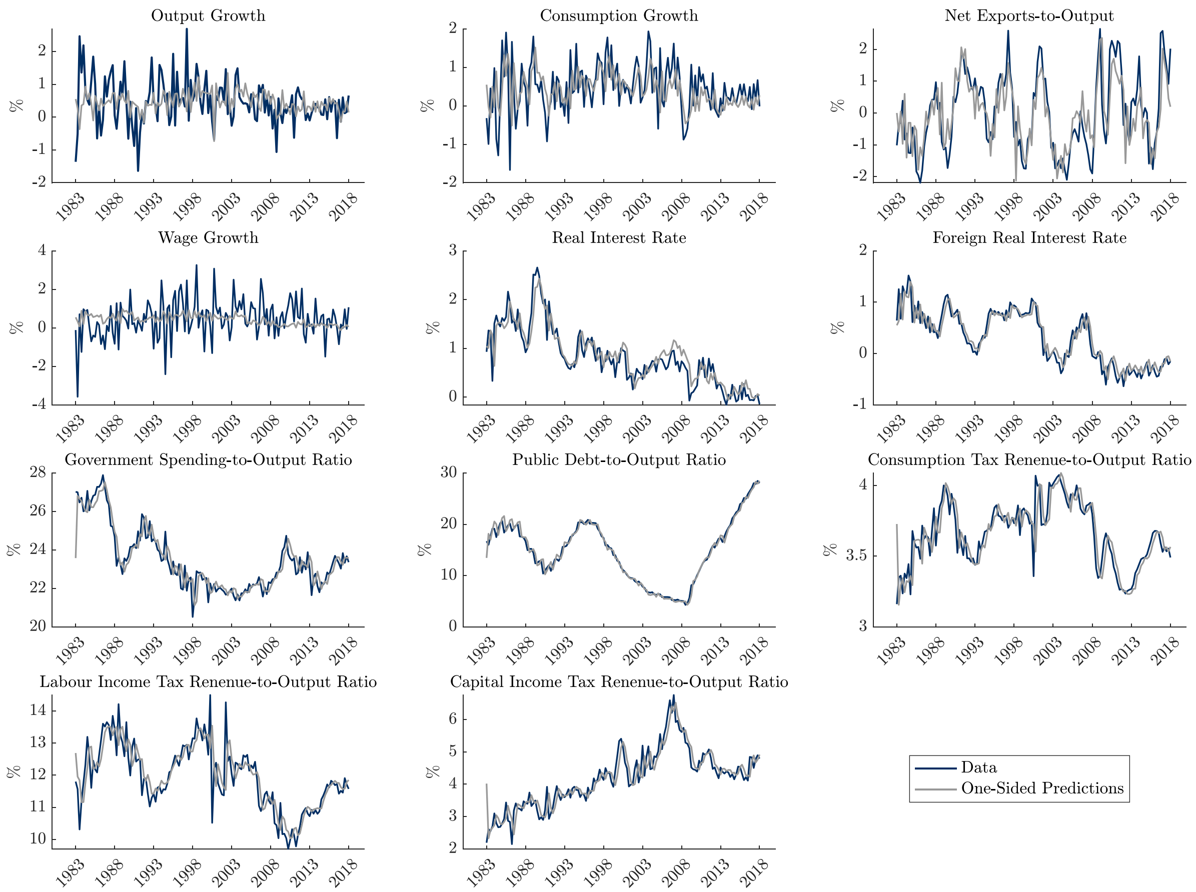

Fig. 4. One-sided predictions and data.
Source: ABS; AOFM; Authors' calculations; FRED; RBA.

5. Model evaluation

Next, we evaluate the estimated model in two key dimensions: in its ability for the one-step ahead predictions and for the estimated transitional dynamics to track observable variables. The transitional dynamics triggered by the slowdown in trend growth are the focus of this paper. It is for this reason and in the interest of space that others dimensions on which we evaluate the model can be found in the online appendix.[19]

5.1. Model fit

The fit of the model at its posterior mode is assessed by comparing, for the observables, one-sided one-step ahead predictions from the model against actual data. As can be seen in Fig. 4, the model tracks the fluctuations in the data closely for the most persistent variables. Wage growth and output growth are quite volatile at a quarterly frequency, and given their lack of persistence, they are naturally hard to predict. Productivity shocks, $\epsilon_{z,t}$, which have a low estimated persistence, $\rho_z = 0.16$, explain a large fraction of the variance of these variables.[20] Because these series have low persistence, the estimated model does a good job relying on non-persistent processes to explain these data, just as the best predictor for a white noise process would simply be its mean. The model does a very good job tracking the fiscal policy variables which indicates that our specification for fiscal policy rules fits the data reasonably well.

[19] In sections G.3 and G.4 of the online appendix we show that the model's investment shocks correlate with measures of corporate interest spreads, suggesting that investment shocks capture changes in financial conditions. We also show that estimated tax shocks line up with important changes in tax rates in our sample.
[20] See the variance decomposition in Section F.4 and IRFs in Section H.1 of the online appendix.

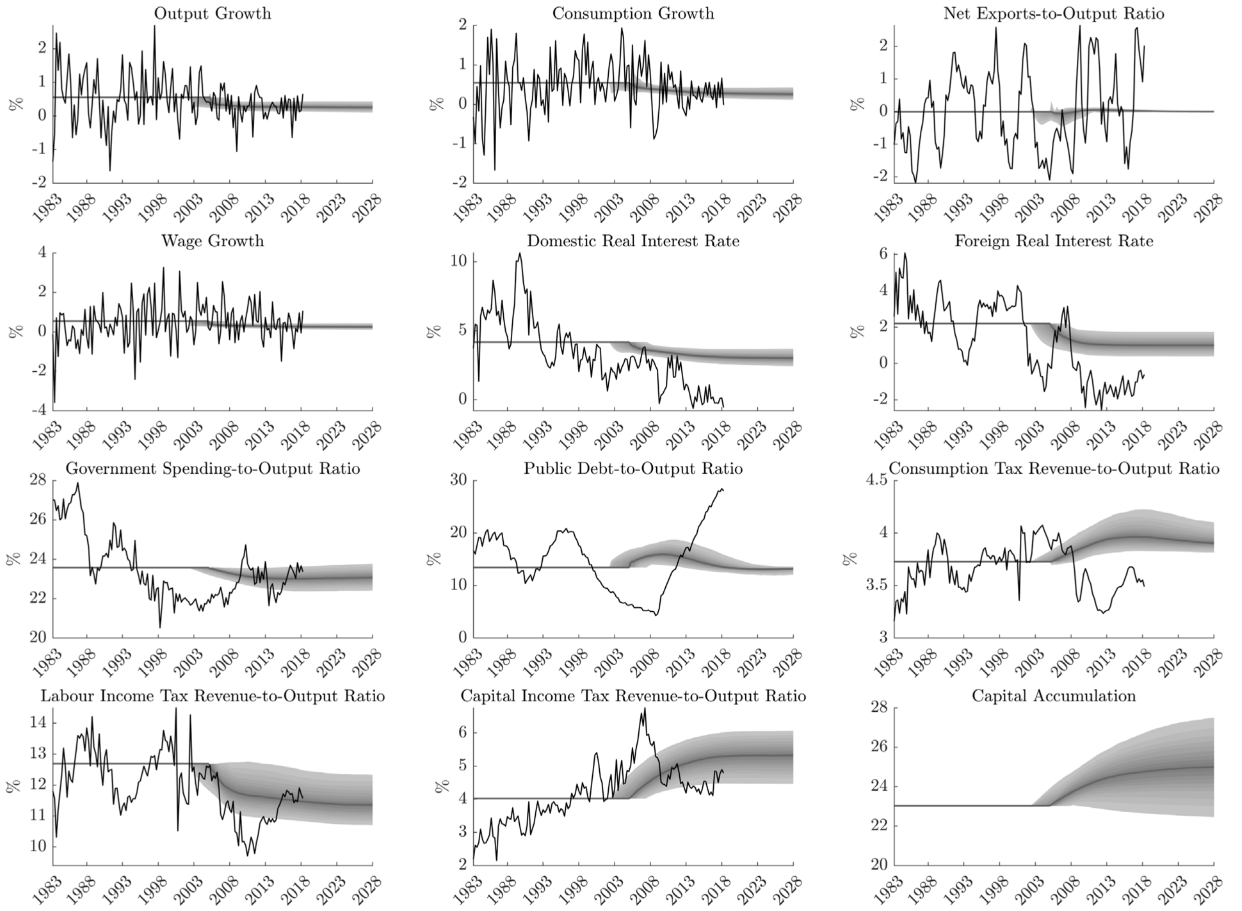

Fig. 5. Data and estimated transitional dynamics. Note: Each entry plots the observed variable (black line) and the non-stochastic transition paths (grey lines). See the online appendix for a description of how the non-stochastic transition paths are computed. The shaded area shows the 95% confidence band for the non-stochastic transition paths. Capital accumulation refers to detrended capital, $k_t = K_t/Z_t$.
Source: ABS; Authors' calculations; FRED; RBA.

5.2. Estimated transitional dynamics

To assess the quantitative implications of the estimated change in trend growth, Δz, we start by computing the transitional dynamics implied by the joint posterior of structural parameters and date breaks. We sample 1000 draws from the posterior and at each draw compute the non-stochastic transition path: the path that the economy would follow in the absence of business cycle shocks, that is $\varepsilon_t = 0$ for all t, but in the presence of regime changes in trend growth from z to $z' = z + \Delta z$, as well as changes in tax rates from τ_w to $\tau'_w = \tau_w + \Delta\tau_w$ and τ_K to $\tau'_K = \tau_K + \Delta\tau_K$ at time T_z. Business cycle shocks can be thought to account for deviations of the observables from these estimated transition paths. The non-stochastic transition paths capture the economy's transition, net of the business cycle shocks, from the initial steady state towards the new steady state.

Fig. 5 plots the posterior distribution of the estimated transitional dynamics for the observable variables used in estimation. Most transition paths start between 2003 and 2005, consistent with the posterior distribution for the date break in trend growth.

The fall in trend growth gives rise to a long-lasting transition towards a new balanced growth path. As trend growth decreases globally, the foreign real interest rate, R^*_t, gradually converges, at the rate of ρ_{R^*}, towards its new lower steady state. In the initial stages of the transition, however, the foreign real rate, R^*_t, falls below the domestic real interest rate. The domestic real interest rate, R_t, takes longer to adjust due to the estimated sources of endogenous persistence: habits in consumption, investment adjustment costs, and fiscal policy rule parameters.

A positive interest rate spread, $R_t > R^*_t$, eventually leads to capital inflows reflected in a deterioration of the trade balance as shown in Fig. 5. If the persistence of the foreign real interest rate, ρ_{R^*}, were sufficiently higher, it would take longer for R^*_t to adjust and R_t could therefore fall below R^*_t on the transition. In this case capital will flow out of the domestic economy and the trade balance would consequently improve. Thus, the relative persistence of the domestic real interest rate to the foreign real interest rate is an important determinant of the response of a small open economy to a global slowdown in trend growth. Across the estimated posterior distribution, however, we find that the trade balance deteriorates in the initial stages of the transition and subsequently recovers to restore the net foreign asset position of the economy.[21]

In our baseline estimation, the fiscal authority leaves the rule for government spending unchanged, in particular the constant g in Eq. (22). This assumption implies that the government spending to output ratio, g/y, gradually falls towards its new steady state. At the mean of the posterior, the government spending to output ratio takes around a decade to converge from its initial steady state value of 23.6 per cent to the lower value of 23.1 per cent.

Thus, when g does not adjust, the g/y ratio falls by 0.5 percentage points. Because the consumption share of output increases in the new balanced growth path, the consumption tax revenue share of output increases by 0.2 percentage points. The permanent decrease in the labour income tax rate to τ_w' reduces the labour income tax revenue share of output by 1.6 percentage points. Meanwhile, the increase in the capital income tax rate to τ_K' raises the capital income tax revenue share of output by 1.5 percentage points. So for the government budget constraint to hold in the long-run, the lump-sum tax share of output must fall by around 0.6 percentage point. The speed with which lump-sum taxes fall towards the new steady state is governed by ρ_τ^1 and ρ_τ^2, which are estimated at 0.19 and 0.16, respectively. The persistence of government spending, ρ_g^1 and ρ_g^2, is significantly higher, 0.64 and 0.31 at the mode, respectively, so government spending as a share of output takes longer than taxes to adjust. And although consumption and capital income tax revenues eventually increase, the fall in labour income tax revenues leads to a primary deficit. As a result of these forces, following the fall in trend growth, there is a rise in the government debt to output ratio.

Tax rates on capital income, labour income and consumption expenditures subsequently respond positively to rising government debt according to Eqs. (23) to (25) helping to restore fiscal balance. The increase in the tax rate on capital income together with the increase of the capital stock fuelled by the rise of investment more than offset the fall in interest rates and so tax revenues from capital income increase as share of output in the transition; eventually, it converges to a higher steady state $\tau_K'\left(\frac{r^K K}{Y}\right) = \tau_K'\alpha$ which in the long-run is independent of z. The increase in the capital stock increases the marginal product of labour which increases real wages. Hours worked on impact increase as consumption falls but the effect is offset by the permanent fall in the labour income tax rate to τ_w'. As a result, tax revenues from labour income fall as a share of output in the transition; and eventually, this share converges to a lower steady state $\tau_w'(1-\alpha)$, which also does not depend on z.

The estimates suggest, given the data, the most likely changes in the government spending to output ratio and in the labour income and capital income tax rates. In the next section, we considers a range of other counterfactual plausible fiscal strategies in response to the slowdown and what their associated implications would be.

6. The fiscal response to the slowdown

As we argue in Section 2, a permanent change in trend growth shifts the balanced growth path and implies a transition towards it. We first discuss how the steady state government budget constraint is affected by trend growth, z, and what options are available for a fiscal authority that satisfies its budget constraint in the long-run. Having pinned down the long-run, we then discuss how the fiscal authority can determine the speed of adjustment towards this new balanced growth path by adjusting the fiscal policy rule response coefficients in Eqs. (22) to (26). We decompose the response of fiscal policy into direct and indirect effects to highlight the role of automatic stabilizers in the transition. We conclude the section by assessing the welfare implications of the slowdown.

In response to the slowdown, the fiscal authority must decide if the current provision of public goods per effective worker is sufficient. If it is, then the constant g in Eq. (22) stays the same. But as output per effective worker rises gradually in the transition towards the new balanced growth path, the government spending share of output, g/y, would decrease gradually as well. Alternatively, the fiscal authority could increase the provision of public goods per effective worker, so as to keep the government spending share of output, g/y, constant across balanced growth paths.[22] Depending on the government spending decision there will be associated implications for taxes, for debt or for both. Unlike the simple government budget constraint of Section 2 which tied spending to lump-sum taxes, the presence of debt and of different taxes generates a range of possibilities for fiscal adjustment.

Whether g/y remains the same or falls in the new steady state, the *level* of government spending, $G_t = gZ_t$, in the new steady state will grow at the lower rate of trend growth, z'. As such, one can think of g, the steady state level of government spending per effective worker, as pinning down the level, while the growth rate of government spending in the long-run is pinned down by the growth rate of Z_t. Thus, whether the government updates g or not, a rule like Eq. (22) captures the proposal of Darvas et al. (2019) according to which expenditures do not grow faster than income in the long-run. But notice that in the short run, the case in which the fiscal authority does not update g implies a transition in which income grows temporarily faster than government expenditures (as g/y is falling) which captures their recommendation for high debt countries.

It is important to bear in mind that options which do not satisfy the government budget constraint in the new long-run are problematic. Assume instead that the fiscal authority were to specify a rule but for the *growth rate* of government spending instead, that is for G_t/G_{t-1}. Imagine also that the fiscal authority were *not to update* its government spending rule when trend growth falls. The outdated growth rule would, of course, lead to explosive debt dynamics as tax revenues would slow down but government spending would not. Such a fiscal regime would not survive the slowdown as it would become inconsistent with the existence of a stable equilibrium. Having made this point, the analysis below is restricted to fiscal rules that are consistent with the existence of a balanced growth path. These rules imply, that in the long-run, a slowdown in trend growth will eventually slow down the growth rates of government spending and of tax revenues to the same extent. The composition of the long-run and the characteristics of the transition towards it, however, depend on how the fiscal authority responds to its new environment. This is what we discuss next.

[21] The spread, $R_t - R_t^*$, is negative in the first quarter of the transition which explains why there is an increase in net exports on impact.

[22] Models of ageing typically predict an increase in government spending per capita. Although we abstract from ageing in the baseline version of the model, we note that the constant g/y case implies an increase in government spending per capita.

Table 4
Fiscal financing scenarios.

	g/y	$p^B b/y$	τ_w	τ_K	τ
Baseline estimation	↓	–	↓	↑	↓
Debt adjusts	↓	↑	–	–	–
τ_w adjusts	↓	–	↓	–	–
τ_K adjusts	↓	–	–	↓	–
Constant g/y	–	–	↓	↑	↓

Note: The table indicates the direction of change in each component of the government's budget constraint from the initial balanced growth path to the final one. A dash (–) signifies no change.

6.1. Counterfactual fiscal policy responses

As in Section 2, a slowdown in trend growth triggers an endogenous response which increases the long-run level of output per effective worker, from y to y' and, with log utility, the consumption to output ratio, c/y, as well. It is clear that fiscal policy must respond somehow to this change in the environment. To understand the options available for fiscal policy, it is useful to consider the government budget constraint in steady state and in terms of shares of output, Eq. (27), which we reproduce below:

$$\frac{g}{y} + \left(\frac{1}{\beta} - 1\right)\frac{p^B b}{y} = \tau_c \frac{c}{y} + \tau_w(1-\alpha) + \tau_K \alpha + \frac{\tau}{y}$$

Take the case in which g stays constant in Eq. (22) and g/y falls as result of the permanent slowdown. This means that for the equation to hold, the term $\left(\frac{1}{\beta} - 1\right)\frac{p^B b}{y}$ must increase or the right hand side, $\tau_c \frac{c}{y} + \tau_w(1-\alpha) + \tau_K \alpha + \frac{\tau}{y}$, must fall, or some combination of both. In the following subsections, we consider alternative fiscal scenarios. Table 4 presents the fiscal scenarios, highlighting which components balance to satisfy the government's budget constraint in steady state.

For the baseline scenario, we take the estimated values of the falls in g/y, τ_w and τ/y and the increase in τ_K. The 'debt adjust' case, for example, keeps the estimated fall in g/y but balances the budget constraint by adjusting the debt to output ratio.

6.1.1. Changing the debt to output target ratio, $p^B b/y$

Fig. 6 uses the estimated posterior mode to illustrate two ways in which the fiscal authority may satisfy the budget constraint in this case.[23] In the first case, labelled 'baseline', τ_w falls and τ_K rises guided by the estimated changes and lump-sum taxes adjust to satisfy the budget constraint, consistent with our baseline specification. In the second case, labelled 'debt adjusts', only the debt to output ratio, $p^B b/y$, increases while the tax rates and lump-sum taxes remain unchanged. With long-term debt, the government must take into account revaluation effects on debt to target a certain debt to output ratio, $p^B b/y$, as the price of long-term debt is determined by trend growth according to $p^B = (z/\beta - \kappa^B)^{-1}$. In the baseline, the debt to output ratio is kept constant across steady states with long-term bond prices higher and the quantity of bonds lower in the final low growth regime.

In the 'baseline' case the fiscal authority keeps the target debt to output ratio, $p^B b/y$, constant, so in order to the satisfy the budget constraint in the new steady state, given the changes in the tax rates τ_w and τ_K, fiscal policy implements a reduction in lump-sum taxes. It is in this sense that the slowdown can give rise to a pleasant fiscal arithmetic. The slowdown triggers an endogenous response of the private sector that increases capital accumulation and increases tax bases. At the estimated values of the fiscal policy rules, the transition towards this new balanced growth implies a mild temporary increase in the debt to output ratio as taxes fall somewhat faster than the g/y ratio given the estimated persistence of government spending.

Alternatively, the fiscal authority could increase the target level of the debt to output ratio, that is, increase $p^B b/y$ to satisfy the government budget constraint in the long-run while keeping the tax rates and lump-sum taxes constant. As in the long run the slowdown decreases g/y but tax revenues to output would remain the same in this case, the slowdown opens up a surplus to output ratio necessary to finance the interest cost of a higher debt to output ratio. At the estimated mode, the slowdown from 2.2% to 0.9% in annual terms, increases the government debt to output ratio from 14 per cent to over 61 per cent in annual terms. The impact on $p^B b/y$ is large because with $\beta = 0.995$, the term $1/\beta - 1 = 0.005$ is small. The transition in this case gives rise to a very pronounced fiscal deficit as tax rates fall in response to the rise in $p^B b/y$. To see this, recall that the fiscal policy rules, Eqs. (22) to (26), all include responses to deviations of the debt to output ratio from target, the terms $\left(by_{t-1} - by\right)$, which call for reducing tax rates when the target debt to output ratio $by \equiv p^B b/y$ increases. In Eq. (22) this term $\left(by_{t-1} - by\right)$ also explains why the g/y ratio converges to its new steady state at a slower pace relative to the 'baseline' case, as the increase in the debt to output target calls for an increase in government spending as well.

Another feature of the 'Debt adjusts' response is that the fiscal authority does not increase the tax rate on capital income, τ_K, as it does in the baseline. As results this fosters capital accumulation and increases output per effective worker even more, which explains why the g/y ratio falls further in this case.

[23] The online appendix reproduces the results in Figs. 6, 7, 8 and 9 and adds 80% confidence bands computed from the posterior distribution. The online appendix also considers the case for which lump-sum taxes adjust for satisfying the budget constraint in the long-run.

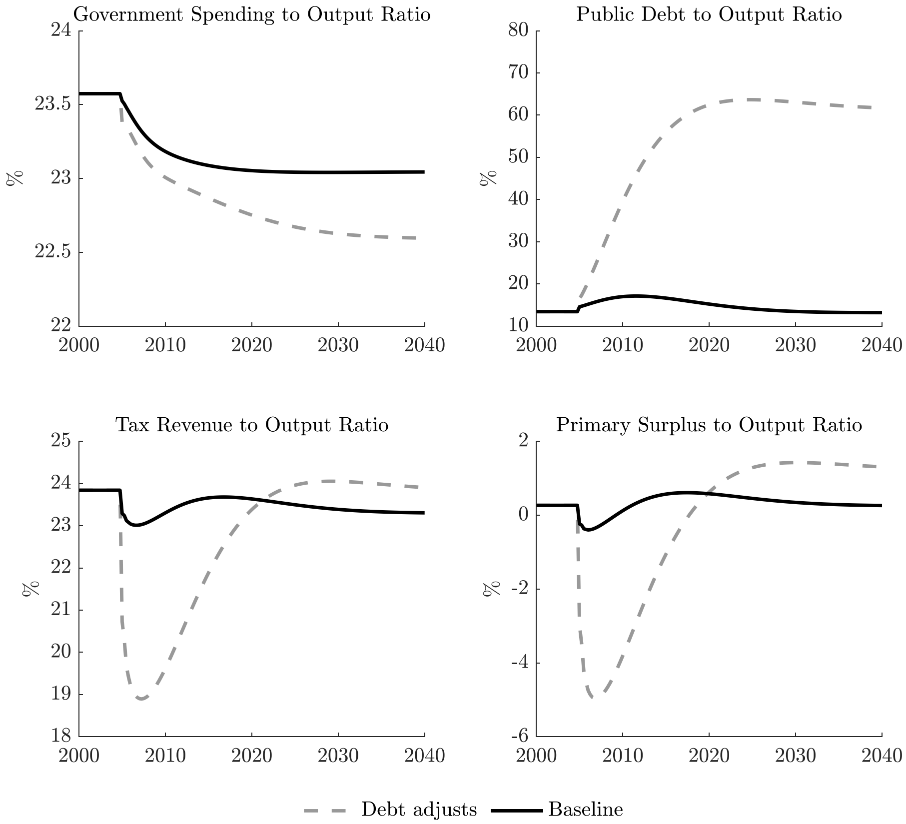

Fig. 6. Changing the debt to output target ratio. Note: The solid-dark line shows the estimated transition dynamics at the mode of the posterior distribution. The dashed-grey line shows the counterfactual transition path where only the debt to output ratio changes to satisfy the government's budget constraint. See the online appendix for a description of how the non-stochastic transition paths are computed.

6.1.2. Changing the tax rate on labour income, τ_w

Fig. 7 illustrates the scenario labelled 'τ_w adjusts', where the government adjusts only the labour income tax rate to satisfy the budget constraint. Compared to the 'baseline' in which τ_w decreases and τ_K rises, this scenario implies a fall in the labour income tax rate while the capital income tax rate remains unchanged. This fiscal response also boosts capital accumulation and output and therefore lowers the government spending to output ratio more, to 22.5%, compared to 23.1% in the baseline case where τ_K is estimated to increase. Higher capital accumulation compared to the baseline increases the real wage, which expands labour supply in the transition. Although the fiscal authority reduces τ_w, the expansion in labour supply boosted by capital accumulation is strong enough that tax revenues from labour income are higher than in the baseline. As a result, the primary deficit is lower following the slowdown in trend growth. Consequently, there is a less pronounced rise in the public debt to output ratio.

6.1.3. Changing the tax rate on capital income, τ_K

Fig. 8 depicts the 'τ_K adjusts' scenario, where the government adjusts only the capital income tax rate while keeping the debt to output ratio and other taxes constant. Compared to the 'baseline' in which τ_K rises, or to cases in which τ_K stays constant, in this case the fiscal authority reduces the tax rate on capital income, boosting capital accumulation even more, leading to an even higher output per effective worker and as a result an even lower terminal government-spending to output ratio, g/y, of 22.1%, compared to 23.1% in the baseline. The increased capital accumulation boosts the marginal product of labour, expanding labour supply. Since in this case the labour income tax rate, τ_w, is unchanged there is no change in the labour income tax revenue to output ratio, $\tau_w(1-\alpha)$. The more pronounced reduction in g/y, implies that the reduction in τ_K results in a lower primary deficit than in the 'baseline' following the slowdown in trend growth; as a result there is only a mild rise in the debt to output ratio.

6.1.4. A constant government spending to output ratio, g/y

Fig. 9 compares the 'baseline' case in which the fiscal authority maintains constant the provision of public goods per capita, g, with the 'constant g/y' case in which the government aims to keep the g/y ratio the same across balanced growth paths. A constant g/y ratio implies that, in the long run, the slowdown has no impact on the left-hand side of Eq. (27). But the composition of tax revenues, the right-hand side of Eq. (27), changes. This is in part because the estimated changes in the tax rates, τ_w and τ_K, are as in the baseline with τ_w falling and τ_K rising. But also because the consumption to output ratio, c/y, increases in response to

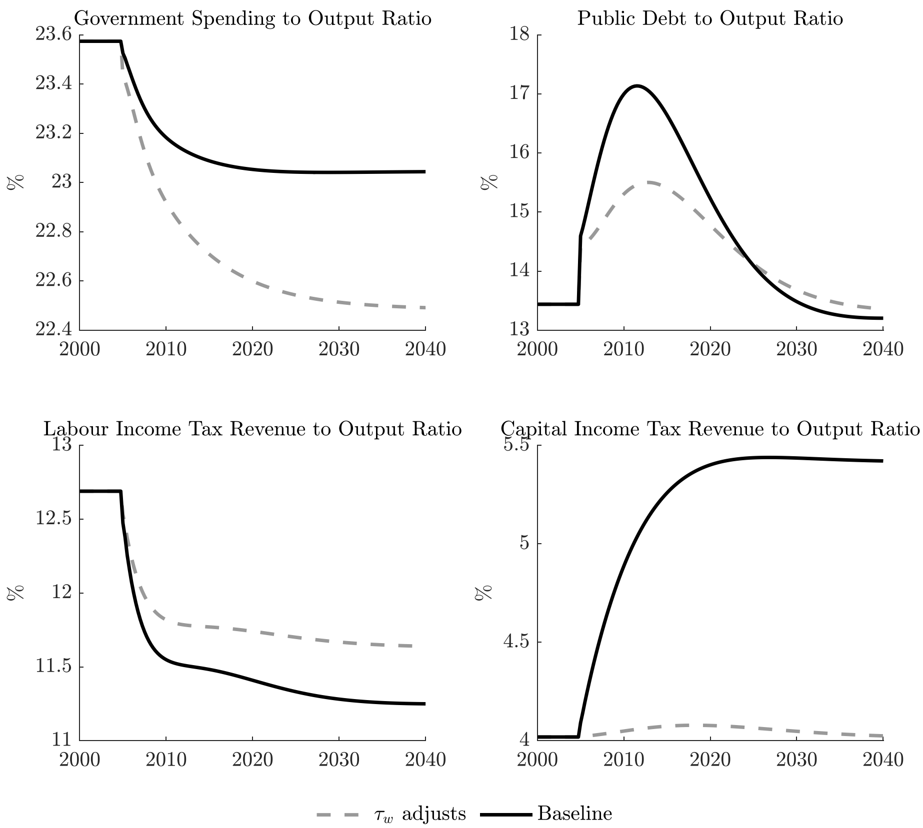

Fig. 7. Labour income tax rate adjusts. Note: The solid-dark line shows the estimated transition dynamics at the mode of the posterior distribution. The dashed-grey line shows the counterfactual transition path where only the labour income tax rate changes to satisfy the government's budget constraint.

the slowdown. Lump-sum taxes, τ/y, in this case fall slightly to balance the budget (from −0.66 percentage points in the baseline to −0.09 percentage points). In the transition, however, tax revenues to output fall driven by cuts to labour income taxes and consequently there is an increase in the debt to output ratio as well. With the target debt to output ratio $p^B b/y$ unchanged, the fiscal rule in Eq. (22) calls for a transitory decrease in government spending, $\log g_t$, in response to the rise in debt to output above its target. The decrease in spending and tax revenues opens up a fiscal deficit initially but then leads to a temporary surplus required to bring back the debt to output to its target ratio.

6.2. The speed of adjustment

Above we discussed alternative ways in which the fiscal authority could adjust fiscal policy so that its budget constraint holds in the long run. Those alternative long-run choices imply different transitions. These transitions were evaluated at the posterior mode of the parameters, including the fiscal policy rule response coefficients, the ρ's and the γ's in Eqs. (22)–(26). These fiscal policy rule coefficients govern the speed of the adjustment towards the new steady state. In particular, the higher the response of the fiscal policy instruments to debt, that is the higher the γ's and the lower their persistence, the lower the ρ's, the faster the economy will converge to its long-run steady state.

To illustrate, in Fig. 10 we take the 'debt adjusts' case and compare the transition under two different settings of the fiscal policy rules. The solid line plots the transition with the parameters of the fiscal policy rules set at the posterior mode of Table 3. In contrast, the dashed line plots the transition where the persistence parameters in the fiscal policy rules are halved from their mode value, while the response coefficients are doubled. These parameter values make the fiscal policy rules more responsive to debt and its instruments less persistent. These rules imply a much faster transition towards the new long-run but comes at the expense of a shorter lived but significantly more pronounced primary deficit in the short-run as can be seen in the bottom right panel of Fig. 10.

6.3. Decomposing the fiscal response

As we highlight in Section 2, the slowdown in trend growth triggers an endogenous response of the private sector. Here we decompose the response of fiscal policy into direct and indirect effects. For example, the level of government spending, $G_t = g_t Z_t$,

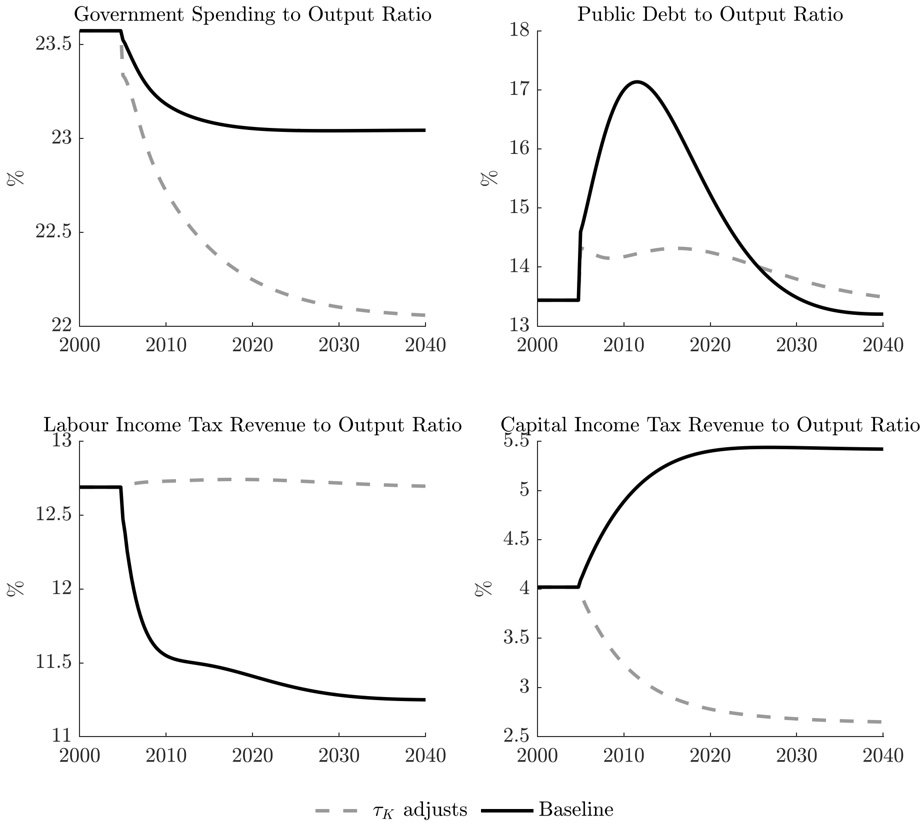

Fig. 8. Capital income tax rate adjusts. Note: The solid-dark line shows the estimated transition dynamics at the mode of the posterior distribution. The dashed-grey line shows the counterfactual transition path where only the capital income tax rate changes to satisfy the government's budget constraint.

can be thought of as composed of a purely exogenous component, Z_t, capturing the direct effect of the slowdown, while g_t, captures the indirect effect as fiscal policy responds endogenously according to Eq. (22). Tax revenues from the various sources can also be decomposed into direct and indirect effects. Take the case of tax revenues from labour income which can be written as $\tau_{w,t} w_t Z_t L_t$ using the fact that $w_t = W_t/Z_t$. In this case there is also a direct effect coming from the slowdown in productivity, Z_t, and indirect effects coming from the endogenous responses of the labour market, w_t and L_t, and from the way fiscal policy adjusts tax rates on labour income, $\tau_{w,t}$, according to Eq. (24). Tax revenues from capital income, $\tau_{K,t} k_t Z_t r_t^K$, can be decomposed in a similar way as is the case with other sources of tax revenue.

Fig. 11 decomposes the responses of spending and tax revenues into exogenous and endogenous components by plotting the deviation from the counterfactual path of no-break in trend growth. This decomposition is done at the estimated mode of the parameter values. As one would expected the direct effects of the slowdown are significant. But when trend growth falls, the indirect effects can be significant as well as households reassess future income and respond by cutting consumption, increasing saving and increasing labour supply in the transition. Capital accumulation boosts real wages and decreases the return on capital. The strong response of capital accumulation, consumption and wages can expand tax bases and help to buffer the slowdown in tax revenues.

The direct effect dominates the response of government spending, with government spending accumulating around a negative 20% deviation from the no-slowdown path towards the end of the sample. The responses of labour income and capital income tax revenues show, however, quite significant indirect effects. In the case of capital income taxes, the increase in the tax rate coupled with increased capital accumulation offset the negative direct effects of the slowdown and of falling real interest rates. In the case of labour income taxes, the reduction in τ_w make the overall indirect effects exacerbate the negative direct effects, in spite of positive indirect effects from real wages and labour supply. and eventually give rise to a reversion towards a primary surplus. As the primary surplus recovers, the debt to output ratio is stabilised and the economy gradually converges to its new balanced growth path.

6.4. Welfare implications of the slowdown

As we suggested earlier, the slowdown in trend growth reduces welfare. Here we breakdown the impact of the slowdown on welfare. One can show that, along the balanced growth path, the representative agent's lifetime utility can be written as follows[24]

[24] See the online appendix for the derivation of the representative agent's lifetime utility function along the balanced growth path.

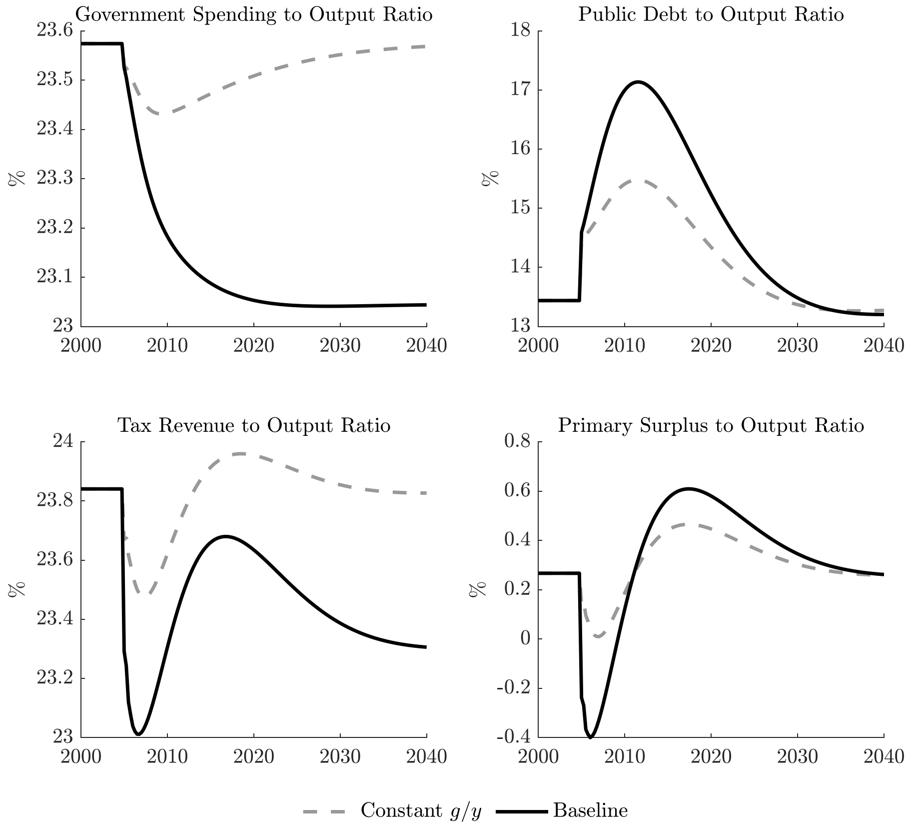

Fig. 9. Constant government spending to output ratio. Note: The solid-dark line shows the estimated transition dynamics at the mode of the posterior distribution. The dashed-grey line shows the counterfactual transition path in which the government maintains the g/y ratio across balanced growth paths.

$$U = \frac{1}{1-\beta}\left[\log(c) - \frac{L^{1+\nu}}{1+\nu} + \log\left(1-\frac{h}{z}\right) + \frac{\beta\log(z)}{1-\beta}\right]$$

Note that the level of consumption, C_t, can be written in terms of detrended consumption and total factor productivity as $c_t Z_t$, which in logs becomes $\log c_t + \log Z_t$. As such, the slowdown also has a direct impact on welfare through Z_t and an indirect impact through c_t and L_t.

Table 5 evaluates welfare at the initial high growth regime (2.2%) and the final low growth regime (0.93%). At the mode and across the posterior distribution lifetime utility is lower in the low growth regime. The indirect effects of trend growth, z, on welfare are captured by the term, $\frac{1}{1-\beta}\log(c) - \frac{1}{1-\beta}\left(\frac{L^{1+\nu}}{1+\nu}\right)$, which depend on consumption and labour choices. The direct effects are captured by the term, $\frac{1}{1-\beta}\left(\log\left(1-\frac{h}{z}\right) + \frac{\beta\log(z)}{1-\beta}\right)$, which depends directly on z.

The decrease in trend growth increases consumption, c, and real wages, w, which in turn reduces hours worked. As shown in the table, a fall in trend growth improves welfare through the indirect effects on c and L. However, these positive effects are dwarfed by the direct effects on welfare. A slowdown in trend growth considerably reduces welfare, yet the endogenous responses work to offset some of the negative impact.

Because in the baseline government spending per effective worker, g, is constant across steady states, the welfare ranking can be expected to hold across steady states even if we were to allow government spending in the utility function, say by adding a term like $\frac{\gamma_g}{1-\beta}\log(g)$, given that the direct effects would work on the same direction.

7. Robustness checks

To assess the robustness of our main results, this section studies the sensitivity of our estimates to alternative model specifications. Specifically, we consider two additional specifications: (i) a model incorporating further financial frictions, allowing for changes in the convenience yield as documented by Del Negro et al. (2019, and (ii)) a model that includes population growth in the model and as an additional observable variable in estimation. As we show below, these robustness checks indicate that the main results remain largely unchanged.

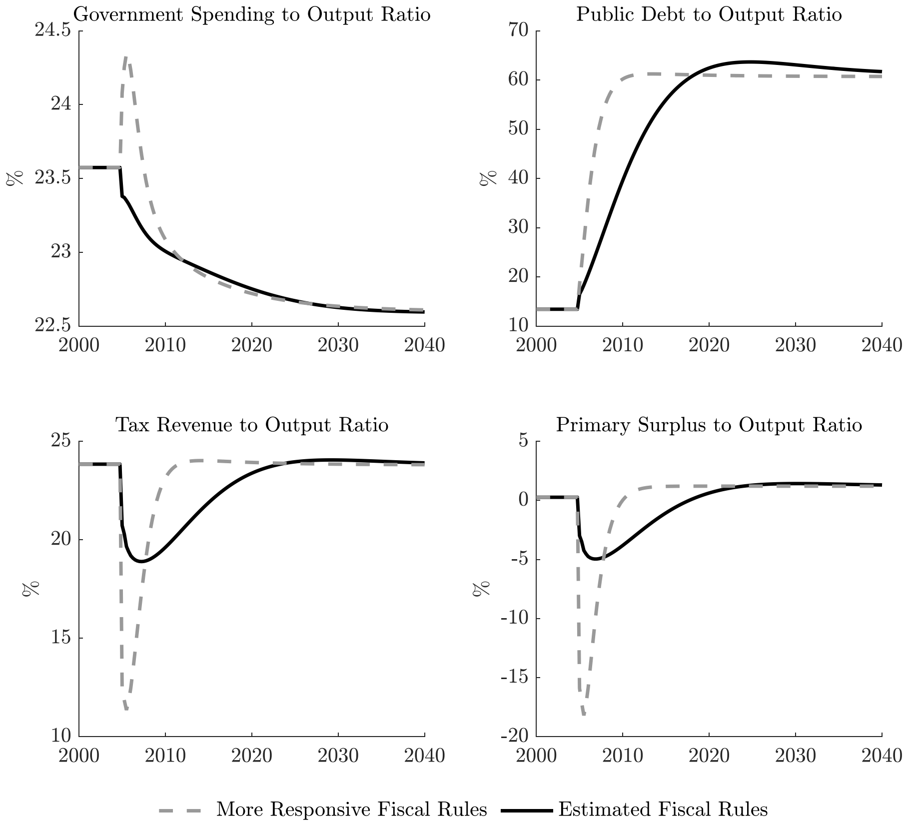

Fig. 10. Speed of fiscal adjustment. Note: The solid-dark line shows the estimated transition dynamics at the mode of the posterior distribution. The dashed-grey line shows the counterfactual transition path with more responsive fiscal policy rules.

Table 5
Welfare implications of the change in trend growth.

	Initial BGP (1)			Final BGP (2)			Change (3) = (2)-(1)		
	Mode	5%	95%	Mode	5%	95%	Mode	5%	95%
Indirect effect	−0.6	−0.7	−0.2	6.7	1.5	22.3	7.3	2.2	22.5
Direct effect	28.0	19.8	80.3	−183.6	−147.0	9.9	−204.3	−371.1	−70.4
Lifetime utility	27.5	19.4	79.9	−160.6	−126.5	13.1	−258.5	−145.9	−66.8

Note: The welfare statistics are computed based on 50,000 draws from the posterior distribution.

Both specifications detect a slowdown in trend growth. The model with financial frictions better accounts for the fall in real interest rates via changes in the convenience yield and results in a less pronounced slowdown. The model with population growth detects a similar slowdown. The mode in all cases falls within the range of the baseline's posterior distribution for Δz.

We also check the robustness of the baseline results by exploring alternative assumptions for the structural breaks and contrasting the estimates with those obtained from a single equation unobserved components model on the real output series alone.

7.1. Model with financial frictions

To account for changes in financial conditions in the aftermath of the global financial crisis, we follow Michaillat and Saez (2021) by adding bonds in the utility function. This modification captures in reduced-form the fact that agents wish to hold government bonds because they offer superior safety and liquidity compared to other assets. The expected lifetime utility is then given by:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \zeta_t \left(\log\left(C_t - hC_{t-1}\right) - \zeta_t^L \frac{L_t^{1+\nu}}{1+\nu} + \chi_b Z_t^{-1} \left(B_t + B_t^F\right) \right) \tag{29}$$

where χ_b determines the convenience yield for domestic and foreign bonds.

Fig. 11. Decomposing the fiscal response. Note: The grey-dotted line plots the percentage deviations in the non-stochastic path of the levels of variables under a scenario with a slowdown in trend growth (Z_t^L grows at a low rate z') relative to a scenario without a slowdown (Z_t^H grows at the initial rate z). The label Z refers to the percentage deviation given by $Z_t^L/Z_t^H - 1$. For example, for the consumption tax revenue, $\tau_{c,t}C_t = \tau_{c,t}c_t Z_t$, we compute percentage deviations for each of its components, that is $\tau_{c,t}^L/\tau_{c,t}^H - 1$, $c_t^L/c_t^H - 1$ and trend growth $Z_t^L/Z_t^H - 1$.

In the modified specification, along the balanced growth path, real interest rates are given by:

$$r = \frac{z}{\beta}\left(1 - \frac{\chi_b}{\lambda}\right) \tag{30}$$

and

$$r^F = \frac{z}{\beta}\left(1 - \frac{\chi_b}{\lambda}\right) \tag{31}$$

where λ is the Lagrangian multiplier on the household's budget constraint. The usefulness of this extension is that lower real interest rates may be stemming from changes in the convenience yield, χ_b (see e.g Del Negro et al., 2017; Neri and Gerali, 2019; Caballero et al., 2021), or changes in productivity growth, z. We re-estimate the model allowing, but not requiring, an additional structural change in the convenience yield from χ_b to $\chi_b' = \chi_b + \Delta\chi_b$.

Table 6 reports the estimates of key structural parameters for both the baseline model and the model with financial frictions. These estimates point towards a break in χ_b around 2008:Q1. This structural change enables the model to track the dynamics of real interest rates in the post-global financial crisis period. The model incorporating financial frictions also estimates a slowdown in trend growth with Δz estimated to be -0.0013, compared to our baseline of -0.0032. The difference can be attributed to the fact that by allowing for a break change in the convenience yield, the model can accommodate lower real interest rates due to factors other than the fall in trend growth. Consequently, this diminishes somewhat the magnitude of the estimated slowdown in growth.

7.2. Model with population growth

Following Weiske (2019) which in turn follows Becker and Barro (1988), we add population to the baseline model. This modification allows the model to capture fertility and mortality shocks, key drivers of ageing. Now, the representative households of size N_t maximises expected lifetime utility given by:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t N_t^{1-\theta} \zeta_t \left(\log\left(\tilde{c}_t - h\tilde{c}_{t-1}\right) - \zeta_t^L \frac{\tilde{l}_t^{1+\nu}}{1+\nu} \right) \tag{32}$$

Table 6
Posterior mode from different model specifications.

	Baseline	Financial frictions	Population growth
Structural parameters			
h	0.57	0.57	0.58
Υ''	2.45	1.66	2.66
ψ_b	0.50	0.45	0.48
Δz	−0.0032	−0.0013	−0.0035
$\Delta\tau_w$	−0.0201	−0.0219	−0.0202
$\Delta\tau_K$	0.0485	0.0511	0.0493
μ	1.89	1.95	1.71
$\Delta\chi_b$		0.0042	
θ			0.42
Fiscal rules parameters			
γ_{gb}	0.026	0.102	0.035
γ_{cb}	0.029	0.032	0.026
γ_{wb}	0.021	0.021	0.026
γ_{Kb}	0.032	0.047	0.028
$\gamma_{\tau b}$	0.053	0.031	0.047
ρ_g^1	0.65	0.65	0.66
ρ_c^1	0.31	0.30	0.31
ρ_w^1	0.70	0.70	0.67
ρ_K^1	0.29	0.28	0.30
ρ_τ^1	0.49	0.48	0.50
ρ_g^2	0.36	0.35	0.35
ρ_c^2	0.67	0.67	0.67
ρ_w^2	0.28	0.27	0.29
ρ_K^2	0.19	0.23	0.18
ρ_τ^2	0.16	0.18	0.15
Date breaks			
T_z	2005:Q1	2005:Q1	2005:Q1
T_σ	2003:Q3	2003:Q3	2002:Q4
T_{χ_b}		2008:Q1	
Log marginal likelihood			
	−5651.5	−5668.7	

where $\tilde{c}_t = C_t/N_t$ is consumption per person and $\tilde{l}_t = L_t/N_t$ are hours worked per person. Following Becker and Barro (1988), the parameter θ represents the weighting factor with respect to household size N_t.[25] The growth rate of the population $n_t = N_t/N_{t-1}$ is assumed to be subject to stochastic shocks $\varepsilon_{n,t}$ and evolves as follows:

$$\log n_t = (1-\rho_n)\log n + \rho_n \log n_{t-1} + \varepsilon_{n,t} \tag{33}$$

In the modified specification, the first-order condition of the household's problem with respect to domestic bonds becomes:

$$\lambda_t = \beta r_t \mathbb{E}_t \left\{ \frac{n_{t+1}^{-\theta}\lambda_{t+1}}{z_{t+1}} \right\} \tag{34}$$

which implies that shocks to fertility can now drive fluctuations in the domestic real interest rate. Furthermore, along the balanced growth path, the real interest rate is given by:

$$r = \frac{zn^\theta}{\beta} \tag{35}$$

[25] The parameter θ is between zero and one for the dynastic lifetime utility function if parents are altruistic and the parent's utility is increasing and concave in the number of children. With $\theta = 0$, the per-capita utility of each generation is weighted by its size (Benthamite preferences). With $\theta = 1$ the per-capita utility of each generation is weighted equally, regardless of its size (Millian preferences).

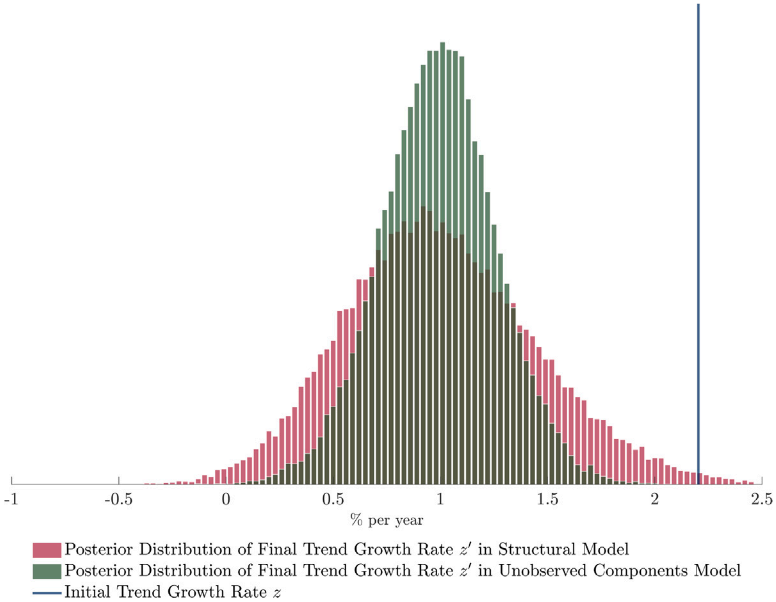

Fig. 12. Posterior distribution of trend growth.

We re-estimate the model making two modifications in the variables used in estimation. First, we introduce Australia's population growth rate as an additional observable. Second, we replace per capita growth rates for output and consumption with aggregate output growth and aggregate consumption growth. Trend growth in output in this case is $z + n$ so the slowdown could come from slowing population growth. However, we did not find a break in population growth in our sample.

Table 6 reports the estimates of key structural parameters for both the baseline model and the model incorporating population growth.[26] The posterior modes and the corresponding 95% confidence intervals in the model with population growth closely resemble those in the baseline model.

7.3. Alternative breaks specifications

Our baseline specification posits a structural break in both trend growth and the variance of shocks. To determine whether our baseline assumptions about the structural breaks provide the best fit for the data and to assess whether different assumptions about the structural breaks would have any implications for the estimated parameters of fiscal rules, we explore four alternative scenarios. In the first scenario, we estimate the model without assuming any structural breaks in either trend growth or the variance of shocks. The second scenario involves a structural break in trend growth but keeps the variance of shocks constant, while the third scenario introduces a structural break in the variance of shocks without altering the level of trend growth. In the final scenario, we estimate the model on the subsample 1983:Q1 to 2006:Q4, which is the period preceding the global financial crisis.

Table 7 reports the estimates of key structural parameters for the baseline model and the specifications with different assumptions about the structural breaks. The log marginal likelihood, which is used as a measure of model fit, suggests that the baseline model, with structural breaks in both trend growth and the variance of shocks, provides the best fit for the data as it has the lowest value of −5651.5. This implies that a model incorporating both types of structural breaks is most compatible with the observed data. Furthermore, the fiscal policy parameters remain relatively consistent across the different scenarios. This suggests that the estimated fiscal policy rules are robust and not significantly affected by the structural break assumptions.

7.4. Single equation estimation

To assess the plausibility of the estimates of Δz we get from the model, we compare them to estimates from a flexible single-equation unobserved components model estimated on the GDP per capita series alone. As we did in the structural model, we allow for a change in trend growth and a change in the variance of shocks.[27] The key result from this exercise is a mode of $z' = z + \Delta z$ at 1.0029 which corresponds to an annual rate of trend growth of 1.16%. The date break is estimated to have taken place in 2008:Q1.

[26] We do not report the log marginal likelihood for the estimation of the model with population growth since it relies on different observable data and is therefore not comparable to the baseline model.

[27] In the interest of space, we relegate the details of this exercise as well as results from the Markov-switching specification of Eo and Morley (2020) to the online appendix.

Table 7
Posterior modes of the structural parameters from different breaks specifications.

Parameter	Baseline	(1)	(2)	(3)	(4)
Structural parameters					
h	0.57	0.59	0.58	0.59	0.59
Υ''	2.45	2.04	2.07	2.42	1.40
ψ_b	0.50	0.57	0.54	0.51	0.48
Δz	−0.0032		−0.0035		
$\Delta\tau_w$	−0.0201		−0.0180		
$\Delta\tau_K$	0.0485		0.0598		
μ	1.89			1.92	
Fiscal rules parameters					
γ_{gb}	0.026	0.079	0.045	0.031	0.041
γ_{cb}	0.029	0.033	0.028	0.030	0.033
γ_{wb}	0.021	0.037	0.023	0.042	0.027
γ_{Kb}	0.032	0.069	0.053	0.063	0.013
$\gamma_{\tau b}$	0.053	0.062	0.059	0.067	0.21
ρ_g^1	0.65	0.64	0.66	0.66	0.64
ρ_c^1	0.70	0.66	0.64	0.71	0.51
ρ_w^1	0.49	0.53	0.47	0.55	0.48
ρ_K^1	0.67	0.67	0.68	0.66	0.65
ρ_τ^1	0.19	0.21	0.20	0.24	0.18
ρ_g^2	0.31	0.30	0.30	0.30	0.34
ρ_c^2	0.29	0.32	0.36	0.28	0.40
ρ_w^2	0.36	0.41	0.36	0.41	0.39
ρ_K^2	0.28	0.28	0.28	0.31	0.31
ρ_τ^2	0.16	0.15	0.15	0.18	0.48
Date breaks					
T_z	2005:Q1		2004:Q3		
T_σ	2003:Q3			2003:Q3	
Log marginal likelihood					
	−5651.5	−5591.2	−5608.6	−5639.5	

Note: (1) reports the results from the estimation without breaks. (2) reports the results from the estimation with a break in trend growth only. (3) reports the results from the estimation with a break in the variance of shocks only. (4) reports the results from the estimation over the sub-sample 1983:Q1-2006:Q4.

The estimate of z' from the unobserved components model is remarkably close to the estimate of z' in the structural model of 0.93% per year, and the posterior distributions of Δz overlap to a large extent as shown in Fig. 12. We also cast the unobserved components model in growth terms and estimate the first-difference specification using GDP per capita growth as an observable. We find that the estimated change in trend growth and date breaks are virtually unaffected in comparison with the estimates obtained using the level of GDP per capita as the observable variable.

8. Conclusion

It seems that trend productivity growth in advanced economies has slowed down. In this paper, we use an estimated stochastic growth model to study the implications of the slowdown for fiscal policy.

An important message of our paper is that to the extent that there is a slowdown, the fiscal regime must adapt. Fiscal policy rules that fix the growth rate of government spending can be troublesome in the face of a slowdown. This is because the fiscal regime becomes inconsistent once the new lower growth regime is in place. The slowdown, however, is not all bad news for the fiscal authority because the endogenous response of the private sector acts like an automatic stabilizer. In fact, if the fiscal authority were to keep the provision of public goods per effective worker fixed, the slowdown requires tax cuts or a higher target for the debt to output ratio. Thus, a low growth environment can support higher levels of the public debt to output but for reasons different than those advanced by Blanchard (2019) which relate to $r < z$. In our case it is always the case that the real interest rate exceeds the rate of growth, $r > z$, but it is private sector's response of increasing capital accumulation that would eventually allow the government to sustain a higher public debt to output ratio.

Our model abstracts from government investment. The main message from our analysis can be expected to hold. The slowdown in that case will also face the fiscal authority with a need to respond. And the response needs to satisfy the budget constraint in the long run. If the government allocates a fraction to investment and the remaining to consumption, the government will have additional ways in which it can satisfy the budget constraint in the long run. But the extent to which government spending would crowd out private spending will depend on the model specification. An analysis of fiscal policy with government investment and capital as in Pappa (2009) is an interesting avenue that we leave for future research.

In our analysis, agents hold model consistent beliefs. This means that once the slowdown takes place, agents update their beliefs and form expectations accordingly. An alternative in which agents learn about the regime over time, as in Eusepi and Preston (2011) or Gibbs and Kulish (2017), is also a worthwhile avenue that we leave for future research.

Finally, we considered permanent changes in trend growth in the neoclassical stochastic growth model in which technology follows an exogenous process. A permanent fall in trend growth triggers an accumulation of capital which in the long run leads to a higher level of output and capital per effective worker. As we argue above, from the perspective of fiscal policy, this endogenous response expands tax bases and works as an automatic stabilizer. In endogenous growth models of the kind proposed by Anzoategui et al. (2019), Bianchi et al. (2019) and Lucas (1988), a permanent fall in trend growth would also trigger a process of capital accumulation and increase capital per effective worker. This is because in response to a slowdown in the productivity of R&D, households would respond endogenously by shifting away from human capital accumulation and towards capital accumulation. But trend growth in endogenous growth models is pinned down, not by a single parameter like z as is the case here, but as a non-linear function of many parameters. Studying permanent changes in trend growth in endogenous growth models and its associated implications for fiscal policy is an exciting avenue that we also leave for future research.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.euroecorev.2024.104806.

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