# Fiscal Policy and the Slowdown in Trend Growth*

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**Abstract**

The slow pace of recovery following the Great Recession raised concerns that trend growth in advanced economies may be permanently lower. Against this background, we set up and estimate a small open economy model with fiscal policy in which trend growth can permanently change. The magnitude and timing of the change in trend growth are estimated alongside the structural and fiscal policy rule parameters. The estimates are used to assess the implications for fiscal policy. Around the second quarter of 2005, trend growth in per capita output is estimated to have fallen from just over to 2 per cent to just below 0.2 per cent per year. The slowdown gives rise to a lasting transition which changes the composition of tax revenues and increases the government debt-to-output ratio.

**JEL Classification:** E30, F43, H30

**Keywords:** Open economy, trend growth, fiscal policy, real business cycles, estimation, structural breaks.

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# 1 Introduction

It is becoming increasingly clear that over the past decade or so the growth rate of output per capita in advanced economies has slowed down. The unexpected slow pace of recovery following the global financial crisis – reflected in weak growth rates of investment, consumption, real wages, and productivity – has led to downward revisions of the growth forecasts of policymakers and professional forecasters.[1]

As Figure 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 are – a slowdown at home and abroad – for a fiscal authority in a small open economy. We do so with an estimated model of the Australian economy, but as Figure 1 shows, our results will be of interest for small open economies more generally.

In spite of the fact that to date the Australian economy has experienced the longest economic expansion on record[2], Australia's economic performance since the global financial crisis has deteriorated: output per capita grew on average at 1 per cent per year over the past decade, compared to the almost 2.5 per cent per year on average prior to the global financial crisis (Figure 1). Despite the 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 recent 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.[3]

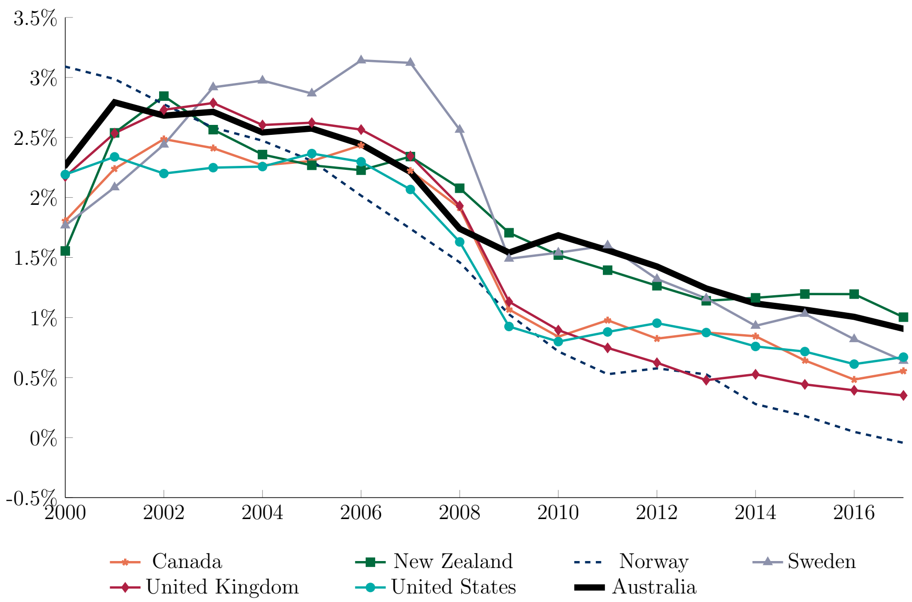
Our work is connected to three strands of the literature. One strand assesses empirically the slowdown in U.S. trend growth: Antolin-Diaz et al. (2016) use a dynamic factor model to document a decline in U.S. trend growth; McCririck and Rees (2016) use a business cycle model that abstracts from fiscal policy and find breaks in productivity growth; and Eo and Morley (2018) using a Markov-switching statistical model detect a reduction in trend growth that began in 2006. Another strand revisits the secular

[1] In its analysis, the International Monetary Fund projects potential growth in advanced economies to average 1.6 per cent per year over the period 2015-2020, well below the pre-crisis average of 2.25 per cent during the period 2001-2007 (IMF, 2015).

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

[3] It is worth noting that the productivity slowdown observed in measures of total factor productivity started around 2004-2005. See 5260.0.55.002 - Estimates of Industry Multifactor Productivity at this link.

Figure 1: Average GDP growth per capita over the past decade:
% per year




Sources: Authors' calculations; FRED

stagnation hypothesis of Hansen (1939): prominent examples are Summers (2015) who argues in support of a demand-side driven interpretation while Cowen (2011) and Gordon (2015) emphasise lower productivity growth as the cause of the recent slowdown; Jones (2018) shows that an aging 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), estimate fiscal policy rules to measure the effects of fiscal policy with fully specified structural models.

This paper is different. Our main contribution is to estimate, with aggregate data and a structural model, the magnitude and timing of the slowdown in trend growth in order to understand the implications for fiscal policy, that is, for government debt, government spending and tax revenues. We use a variant of the canonical small open economy stochastic growth model that we extend to include a fiscal authority that levies lump-sum transfers, as well as taxes on labour income, capital income and consumption expenditures in order to fund interest payments on accumulated government liabilities and general government expenditures. The sole cause of a permanent slowdown in our model is a permanent fall of the growth rate of labour-augmenting technology, which is consistent with a growth accounting exercise which shows that the bulk of the slowdown can be attributed to slowing total factor productivity.[4]

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 GDP per capita started to fall around 2005 from just over 2 per cent towards our current estimate of just below 0.2 per cent per year. This contrasts with results from an unobserved components model estimated on the GDP per capita series alone. We also detect a slowdown, although a less pronounced one, with trend growth estimated to have fallen to 1 per cent per year. As we discuss below, bringing additional series to the estimation of a structural model, in particular, the trade balance, the real interest rate and the government spending-to-output ratio, contribute to the lower estimate of trend growth that we find.

The estimated model is used to quantify how the slowdown affects the economy. Because the slowdown is global, both foreign and domestic real interest rates fall. But the estimates suggest that the domestic real interest rate stays above the foreign real interest rate for most of the transition which leads to a deterioration of the current account. 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 which deteriorates the primary deficit and increases the government debt-to-output ratio. Below, the implications are discussed in full, including the importance of assumptions regarding the size of government in the presence of a changing balanced growth path.

We use the method of Kulish and Pagan (2017) to allow, but not to impose, in structural estimation a break in the growth rate of labour-augmenting productivity. As such, the likelihood function is free to choose what change in trend growth, if any, best fits the data. This strategy is also used by Kulish and Rees (2017) to estimate changes in the long-run level of the terms of trade. Aguiar and Gopinath (2007) use consumption and net exports to identify the contributions of permanent and transitory shocks to the level 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 model also has these permanent shocks to productivity, but we allow for a break in trend growth. Like these papers, we rely on many observables to achieve identification: real GDP per capita growth, real investment per capita growth, net exports-to-GDP, government

[4]See Appendix B.

spending-to-GDP, a measure of the real interest rate, government debt-to-GDP, real wage growth, consumption tax revenue-to-GDP, labour income tax revenue-to-GDP and capital income tax revenue-to-GDP.

In Section 2 we develop intuition with the Ramsey model to understand the economic forces triggered by a permanent slowdown in trend growth. We then discuss two assumptions regarding the fiscal policy response to the slowdown that we take to the data with the small open economy model that is set up in Section 3. Section 4 presents the data. Section 5 contains the main results and in Section 6 we conclude proposing avenues for further research.

# 2 Trend Growth in the Neoclassical Model

It is useful to build intuition for the empirical exercise that follows by first considering a slowdown in trend growth in the textbook closed economy Ramsey-Cass-Koopmans model (Ramsey (1928), Cass (1965) and Koopmans (1963)). The continuous time neoclassical growth model is well-known, so we restrict our attention to those equations needed to convey our point.[5] As we discuss below, the main point with the closed economy model carries over to the open economy case as well.

Output is produced according to $Y = K^{\alpha}\left(ZL\right)^{1-\alpha}$, 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 $u(c) = \frac{c^{1-\sigma}-1}{1-\sigma}$ and $\rho$ is the subjective discount rate.[6] The competitive equilibrium yields paths for consumption and the capital stock that solve the system of differential equations below.

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

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

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

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

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

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 Equation (3). In other words, $\frac{\partial \bar{k}}{\partial z} < 0$. Using Equation (3) in (4) it may be shown that

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

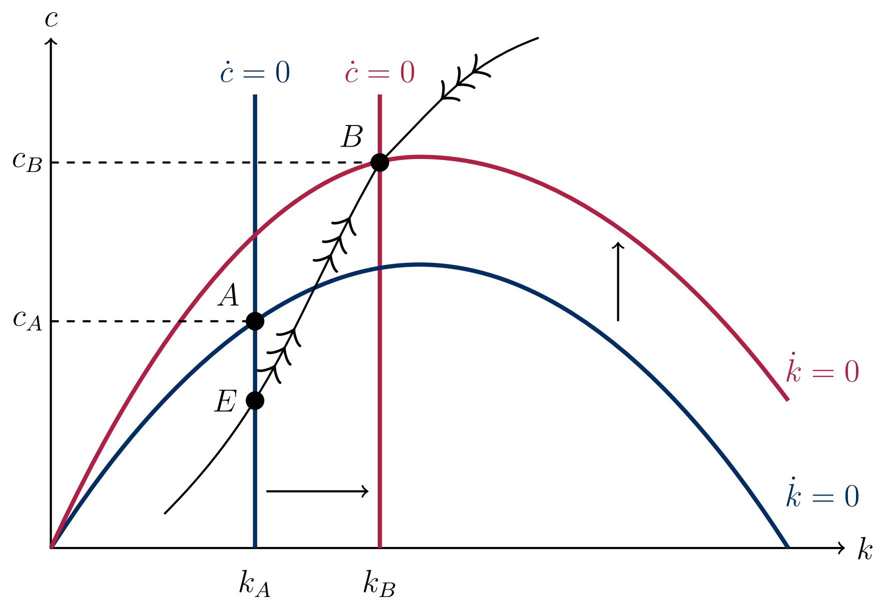
and so consumption per unit of effective labour also increases following the fall in trend growth.

Figure 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, Equation (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 $z$ acts as an increase in the real interest rate, it implies that the net rate of return on capital is above its steady state value, giving households the incentive to reduce consumption today and increase it in the future. 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.

Figure 2: Fall in Trend Growth in the Basic Ramsey-Cass-Koopmans Model




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

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

where $g$ is government spending and $\tau$ are lump-sum taxes both expressed in terms of effective labour units. The competitive equilibrium with fiscal policy yields the paths for consumption and the capital stock that solve Equation (1) and the modified version of Equation (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 Equation (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 is thought to be pinned down in steady state. We consider the following two cases which we take to the data below. The first, assumes government spending is set so that in steady state the government spending-to-output ratio is $\gamma$, that is

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

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

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

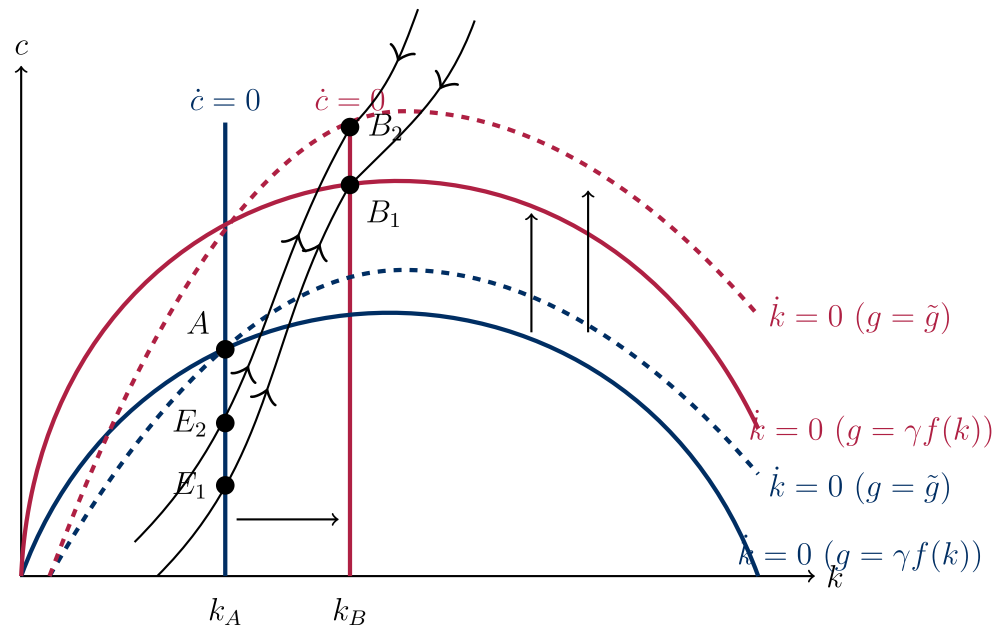
A fall in $z$ increases $\bar{k}$ and $\bar{y} = f(\bar{k})$ by the same amount in both cases. But when the government follows Equation (7), the fall in $z$ leads to an increase in $g$ so that the size of government in the final steady state stays at $\gamma$. In the transition, the size of government would exceed $\gamma$ because Equation (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 Equation (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 $\gamma$ following the fall in trend growth.

Figure 3 compares the transitional dynamics following a fall in $z$ when the government follows Equation (7) with those obtained when the government follows Equation (8). 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 Equation (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 Equation (8) than under Equation (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 (Figure 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.

In the next section, we set up an empirically plausible small open economy stochastic growth model with government debt, lump-sum taxes as well as distortionary taxes on consumption, labour and capital income, habits in consumption and shocks to preferences, technologies and fiscal instruments. In that model, however, the way government spending responds to the change in trend growth determines transitional dynamics and the long-run properties of the economy in terms of the consumption to output and the government spending to output ratios in the same way as we discussed above.

Figure 3: Fall in Trend Growth with Fiscal Policy




# 3 A Small 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

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

subject to the period budget constraint:

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

and the capital accumulation equation:

$$K_t = (1-\delta)\,K_{t-1} + \zeta_t^I \left[1 - \Upsilon\left(\frac{I_t}{I_{t-1}}\right)\right] I_t \tag{9}$$

In the equations above, $C_t$ is consumption, $\tau_t^c$ is the tax rate on consumption, $I_t$ is investment, $B_t$ stands for government bonds and $R_t$ for its gross rate of return, $B_t^F$ 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 $\tau_t^w$ 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 $\tau_t^K$ 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. $\zeta_t$ is an intertemporal preference shock that follows:

$$\ln \zeta_t = \rho_\zeta \ln \zeta_{t-1} + \varepsilon_{\zeta,t} \tag{10}$$

and $\zeta_t^L$ is a labour supply shock that follows:

$$\ln \zeta_t^L = \rho_L \ln \zeta_{t-1}^L + \varepsilon_{L,t} \tag{11}$$

$\zeta_t^I$ is a shock to the marginal efficiency of investment which is assumed to follow:

$$\ln \zeta_t^I = \rho_I \ln \zeta_{t-1}^I + \varepsilon_{I,t} \tag{12}$$

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:

$$Y_t = K_{t-1}^\alpha \left(Z_t L_t\right)^{1-\alpha} \tag{13}$$

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

$$\ln z_t = (1-\rho_z)\ln z + \rho_z \ln z_{t-1} + \varepsilon_{z,t} \tag{14}$$

and so $z$ governs the labour-augmenting growth rate of TFP along the balanced growth path. In the empirical application we allow, but do not impose, $z$ to change at some point in the sample from $z$ to $z' = z + \Delta z$. Below, $z$ is calibrated and $\Delta z$ estimated.

### 3.2 The Government

The government receives tax payments on consumption, labour and capital income as well as lump-sum taxes and borrows domestically to finance government spending. Thus, the government budget constraint is

$$B_t + \tau_t^c C_t + \tau_t^w W_t L_t + \tau_t^K r_t^K K_{t-1} + TR_t = R_{t-1} B_{t-1} + G_t \tag{15}$$

We assume the government sets government spending and taxes rates following fiscal rules which include a response to deviations of the government debt-to-output ratio from its steady state. In particular, we assume rules of the form:

$$\ln g_t = (1-\rho_g)\ln g + \rho_g \ln g_{t-1} - (1-\rho_g)\gamma_{gb}\left(\frac{b_{t-1}}{y_{t-1}} - \frac{b}{y}\right) + \varepsilon_{g,t} \tag{16}$$

$$\tau_t^c = (1-\rho_c)\tau_c + \rho_c \tau_{t-1}^c + (1-\rho_c)\gamma_{cb}\left(\frac{b_{t-1}}{y_{t-1}} - \frac{b}{y}\right) + \varepsilon_{c,t} \tag{17}$$

$$\tau_t^w = (1-\rho_w)\tau_w + \rho_w \tau_{t-1}^w + (1-\rho_w)\gamma_{wb}\left(\frac{b_{t-1}}{y_{t-1}} - \frac{b}{y}\right) + \varepsilon_{w,t} \tag{18}$$

$$\tau_t^K = (1-\rho_K)\tau_K + \rho_K \tau_{t-1}^K + (1-\rho_K)\gamma_{Kb}\left(\frac{b_{t-1}}{y_{t-1}} - \frac{b}{y}\right) + \varepsilon_{K,t} \tag{19}$$

$$\tau_t = (1-\rho_\tau)\tau + \rho_\tau \tau_{t-1} + (1-\rho_\tau)\gamma_{\tau b}\left(\frac{b_{t-1}}{y_{t-1}} - \frac{b}{y}\right) + \varepsilon_{\tau,t} \tag{20}$$

where the normalised variables $\tau_t = \frac{TR_t}{Z_t}$, $y_t = \frac{Y_t}{Z_t}$, $g_t = \frac{G_t}{Z_t}$, $b_t = \frac{B_t}{Z_t}$, have steady states $\tau, y, g$ and $b$ respectively.

### 3.3 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:

$$R_t^F = R_t^* \exp\left[-\psi_b\left(\frac{b_t^F}{y_t} - \frac{b^F}{y}\right)\right] \tag{21}$$

where $\frac{b^F}{y}$ is the steady-state ratio of net foreign assets-to-output and $R_t^*$ is the foreign real interest rate which follows the exogenous process below:

$$\ln R_t^* = (1 - \rho_{R^*}) \ln R^* + \rho_{R^*} \ln R_{t-1}^* + \varepsilon_{R^*,t} \tag{22}$$

In steady state, the foreign real interest rate, $R^*$, is $z/\beta$. Our assumption that the slowdown is global is reflected in the fact that when trend growth falls so will $R^*$. However, $R_t^*$ will converge gradually, governed by $\rho_{R^*}$, to its lower steady state. Equation (21) shows that if $R_t^F$ were to exactly track $R_t^*$ then net foreign assets would stay constant. If, however, due to frictions like 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,

$$NX_t = Y_t - C_t - I_t - G_t \tag{23}$$

and the current account is therefore given by:

$$CA_t = NX_t + (R_{t-1}^F - 1)B_{t-1}^F \tag{24}$$

In equilibrium, the evolution of the net foreign assets evolves according to

$$B_t^F = R_{t-1}^F B_{t-1}^F + NX_t \tag{25}$$

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. Next, we discuss how fiscal policy is determined with a changing steady state.

### 3.4 The Government Budget Constraint with Changes in the Steady State

In steady state, the government budget constraint, Equation (15), expressed in terms of shares of output becomes:

$$\frac{g}{y} + \left(\frac{1}{\beta} - 1\right)\frac{b}{y} = \tau_c \frac{c}{y} + \tau_w(1-\alpha) + \tau_K \alpha + \frac{\tau}{y} \tag{26}$$

where we have used the fact that with a Cobb-Douglas production function the labour share of income is $1-\alpha$ and the capital share of income is $\alpha$.

In the absence of any permanent tax reforms, a permanent decrease in trend growth, from $z$ to the lower value of $z'$, has no impact on the long-run values of the tax revenue shares of output from labour and capital income: the term $\tau_w(1-\alpha) + \tau_K\alpha$ does not depend on $z$. But as argued in Section 2, the consumption share of output, $c/y$, increases in the new balanced growth path.[7] If the government spending-to-output ratio and the debt-to-output ratio were to remain constant across steady states, so that

$$\frac{g}{y} = \frac{g'}{y'} \text{ and } \frac{b}{y} = \frac{b'}{y'}$$

then lump-sum transfers-to-output must fall to some lower value, say $\tau'/y'$, to offset the increase in the consumption tax revenue, $\tau_c c'/y'$, and satisfy the government budget constraint in the long-run.

In the empirical application that follows, a permanent fall in $z$ leads to an increase in the steady state value of detrended output from $y$ to $y'$ as is the case in Section 2. Whether the government spending share of output remains the same depends on whether the fiscal authority updates its fiscal policy rule parameter $g$ in Equation (16). If the fiscal authority recognises the regime change when it happens, the constant in Equation (16) increases to $g'$ so that in the new balanced growth path the government spending share of output is back to the same value, that is $g/y = g'/y'$. During the transition, the increase to $g'$ implies a gradual increase in government spending according to Equation (16). If the fiscal authority does not adjust $g$ in Equation (16) when the change in trend growth happens, the government spending-to-output ratio gradually decreases in the transition towards a lower value, $g/y'$. In both cases, lump-sum transfers are assumed to adjust to satisfy the government budget constraint in the long-run. Below we take both hypotheses regarding the adjustment of $g$ to the data and find that the specification for

[7] This is the case with log utility.

which the government spending-to-output ratio gradually decreases fits the data better. We therefore take the case in which $g$ remains constant in Equation (16) as our baseline specification.

# 4 Empirical Analysis

The model in Section 3 is linearised around its non-stochastic steady state and the method of Kulish and Pagan (2017) is used to solve and estimate the model in the presence of structural breaks.

The structural parameters can be categorised as either having only an impact on the dynamics of the model – persistences of shock processes, adjustment costs, fiscal policy rule 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 the data and estimate the first category of parameters together with $h$, the consumption habit parameter, and $\Delta z$, the change in the steady state growth rate between the initial and final steady state.

## 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 $\Delta z$ is estimated. Given $z$, we then set $\beta$ to match the mean of the real interest rate in the data, 4.2 per cent in annual terms. The production function parameter, $\alpha$, is set to match the mean of the investment and consumption-to-output ratios. The depreciation of capital, $\delta$, 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 per cent. 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. The government spending to output ratio is chosen to correspond to total government spending (consumption plus investment) in the data.[8] Finally, we set the inverse Frisch elasticity of labour supply, $\nu$, to 2, which is standard in the literature. Table 1 summarises the values of the calibrated parameters.

Table 2 shows the resulting calibration by comparing model moments with those in the data for the pre-financial crisis sample. We choose to match the moments in the

[8] 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).

Table 1: Calibrated Parameters

| Parameter | Description | Value |
|---|---|---|
| $\beta$ | Household discount factor | 0.996 |
| $\delta$ | Capital depreciation rate | 0.016 |
| $\nu$ | Inverse Frisch | 2 |
| $z$ | Steady-state TFP growth | 1.0055 |
| $\alpha$ | Capital share in production | 0.29 |
| $b^*$ | Steady-state net foreign assets | 0 |
| $g/y$ | Steady-state government spending-to-output | 0.23 |
| $b/y$ | Steady-state debt-to-output | 0.56 |
| $\tau^c$ | Steady-state consumption tax rate | 0.06 |
| $\tau^w$ | Steady-state labour income tax rate | 0.17 |
| $\tau^K$ | Steady-state capital income tax rate | 0.13 |
| $\psi_b$ | Risk premium sensitivity | 0.01 |

pre-crises 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, Equation (25) 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 also had a negative net foreign asset position. Because of this reason we decided to strike a balance and set the net foreign asset position to zero in steady state, which implies balanced trade.

## 4.2 Estimation

In estimation we follow the literature on estimated dynamic stochastic general equilibrium models.[9] 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, $\theta$, 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 and $T_\sigma$ is the date break in the variance of shocks[10]. To capture the great moderation, the fact that the variance of macroeconomic aggregates has fallen, we use a parsimonious specification and introduce the parameter $\mu$, which multiplies all standard

[9] See An and Schorfheide (2007) for a description of these techniques.

[10] See Kulish and Pagan (2017) for the general methodology of solving and estimating models under structural change; the online appendix of Kulish and Rees (2017) discusses an application to a particular case similar to ours.

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 |
| **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) | | |
| Public Debt | 13.4 | 13.4 |

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

deviations before $T_\sigma$, i.e. the standard deviations of all variables are assumed to shift in the same proportions. Both $\mu$ and $T_\sigma$ are then estimated.

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

$$P(\theta, \mathbf{T}|\mathbf{Y}) \propto \mathbf{L}(\mathbf{Y}|\theta, \mathbf{T})p(\theta, \mathbf{T}), \tag{27}$$

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 the initial regime (high trend growth and variances) is at least 60 quarters long. 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 quarterly Australian macroeconomic time series for the period 1983:Q1 to 2018:Q1. Real GDP and investment are seasonally adjusted and measured in chain volume terms, while government spending[11] and net exports are

[11] 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

seasonally adjusted and measured in current prices. Output and investment are expressed in per capita terms by dividing by the population derived from the GDP per capita series. These series enter in first differences, while government spending and net exports enter as shares of nominal GDP. The sample mean of investment 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 interest rate is the 90-day bank bill rate. This nominal interest rate is converted to a real rate using the trimmed mean inflation series.

The measure of public 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

We choose a uniform prior with a wide support of $-0.01$ to $0.01$ for $\Delta z$ which corresponds to the parameter of most interest in this analysis. 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 terms translates to a range between $-1.8$ to 6.2 per cent.

Other choices follow the literature: Beta distributions for the persistence coefficients and Inverse Gamma distributions for the standard deviations of the shocks. In the case of 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.

receipts) is a residual implied by the government budget constraint (Equation (15)).

Table 3: Prior and Posterior Distribution of the Structural Parameters

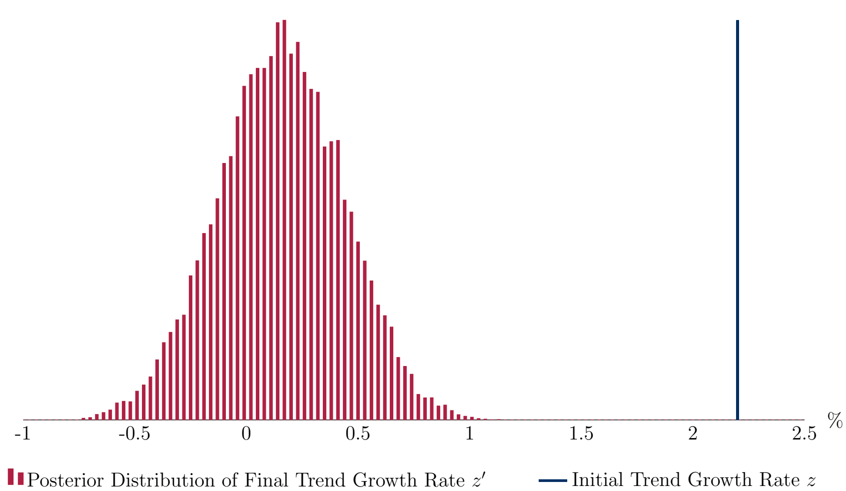
| | Prior distribution | | | Posterior distribution | | | |
|---|---|---|---|---|---|---|---|
| Parameter | Distribution | Mean | S.d. | Mean | Mode | 5% | 95% |
| **Structural Parameters** | | | | | | | |
| $h$ | Beta | 0.5 | 0.25 | 0.12 | 0.11 | 0.05 | 0.21 |
| $\Upsilon''$ | Normal | 5.0 | 2.0 | 3.39 | 2.99 | 2.19 | 4.92 |
| $\Delta z$ | Uniform | [-0.01, 0.01] | | -0.0051 | -0.0051 | -0.0063 | -0.0040 |
| $\mu$ | Uniform | [0, 3] | | 2.28 | 2.22 | 2.00 | 2.60 |
| $\gamma_{gb}$ | Uniform | [0, 0.5] | | 0.07 | 0.02 | 0.01 | 0.18 |
| $\gamma_{cb}$ | Uniform | [0, 0.5] | | 0.00 | 0.00 | 0.00 | 0.01 |
| $\gamma_{wb}$ | Uniform | [0, 0.5] | | 0.04 | 0.02 | 0.01 | 0.08 |
| $\gamma_{Kb}$ | Uniform | [0, 0.5] | | 0.05 | 0.01 | 0.00 | 0.11 |
| $\gamma_{\tau b}$ | Uniform | [0, 0.5] | | 0.06 | 0.06 | 0.01 | 0.11 |
| **AR Coefficients** | | | | | | | |
| $\rho_z$ | Beta | 0.50 | 0.19 | 0.24 | 0.27 | 0.14 | 0.34 |
| $\rho_{R^*}$ | Beta | 0.71 | 0.16 | 0.62 | 0.62 | 0.56 | 0.69 |
| $\rho_\zeta$ | Beta | 0.71 | 0.16 | 0.96 | 0.98 | 0.92 | 0.99 |
| $\rho_L$ | Beta | 0.71 | 0.16 | 0.99 | 0.99 | 0.99 | 0.99 |
| $\rho_I$ | Beta | 0.50 | 0.19 | 0.18 | 0.17 | 0.07 | 0.31 |
| $\rho_g$ | Beta | 0.71 | 0.16 | 0.94 | 0.95 | 0.89 | 0.97 |
| $\rho_c$ | Beta | 0.71 | 0.16 | 0.86 | 0.87 | 0.78 | 0.94 |
| $\rho_w$ | Beta | 0.71 | 0.16 | 0.87 | 0.89 | 0.81 | 0.92 |
| $\rho_K$ | Beta | 0.71 | 0.16 | 0.92 | 0.93 | 0.88 | 0.95 |
| $\rho_\tau$ | Beta | 0.50 | 0.19 | 0.23 | 0.21 | 0.11 | 0.35 |
| **Standard Deviations** | | | | | | | |
| $\sigma_z$ | Inv. Gamma | 0.01 | 0.30 | 0.009 | 0.009 | 0.008 | 0.010 |
| $\sigma_{R^*}$ | Inv. Gamma | 0.01 | 0.30 | 0.002 | 0.002 | 0.002 | 0.002 |
| $\sigma_\zeta$ | Inv. Gamma | 0.10 | 0.30 | 0.029 | 0.023 | 0.018 | 0.045 |
| $\sigma_L$ | Inv. Gamma | 0.10 | 0.30 | 0.028 | 0.028 | 0.025 | 0.032 |
| $\sigma_I$ | Inv. Gamma | 0.10 | 0.30 | 0.088 | 0.079 | 0.058 | 0.125 |
| $\sigma_g$ | Inv. Gamma | 0.10 | 0.30 | 0.023 | 0.023 | 0.021 | 0.026 |
| $\sigma_c$ | Inv. Gamma | 0.01 | 0.30 | 0.001 | 0.001 | 0.001 | 0.002 |
| $\sigma_w$ | Inv. Gamma | 0.01 | 0.30 | 0.007 | 0.006 | 0.006 | 0.007 |
| $\sigma_K$ | Inv. Gamma | 0.01 | 0.30 | 0.009 | 0.009 | 0.008 | 0.011 |
| $\sigma_\tau$ | Inv. Gamma | 0.10 | 0.30 | 0.063 | 0.064 | 0.057 | 0.071 |
| Log marginal density: 4703.3 | | | | | | | |

# 5 Results

## 5.1 Structural Parameters and Date Breaks

The estimates of the structural parameter for our preferred specification are shown in Table 3. Staring with our parameter of most interest, $\Delta z$, there is strong evidence in favour of slowdown in trend growth. Figure 4 shows the posterior distribution of $z' = z + \Delta z$ together with sample mean of trend growth for the period 1983-2008 which is our calibrated value for trend growth in the initial regime. After the break, trend growth in GDP per capita in annual terms is estimated to be around 0.16% at the mode of the posterior. And while there is some uncertainty around this estimate, there is no mass close to the trend growth rate of the initial regime.

Figure 4: Posterior Distribution of Trend Growth

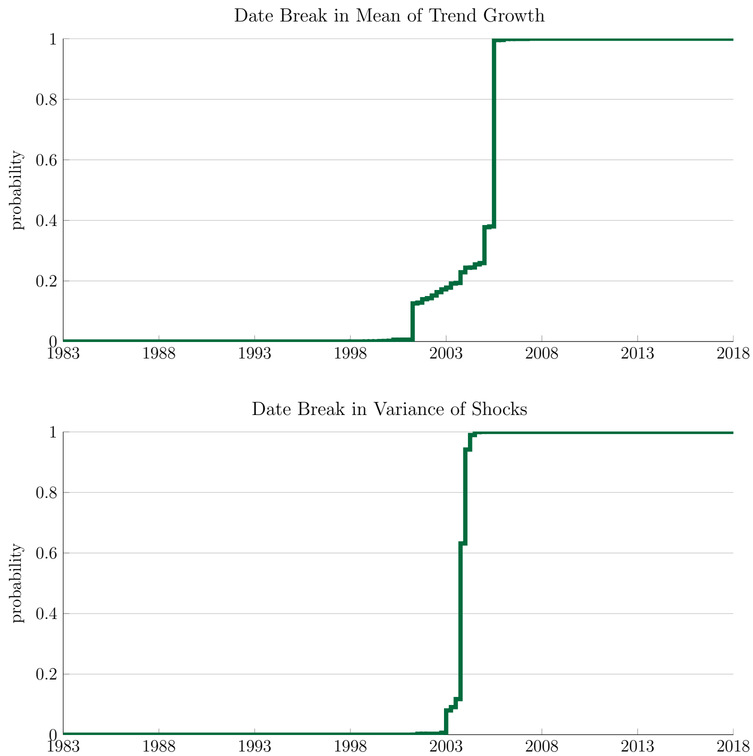



The top panel of Figure 5 shows the estimated cumulative distribution function for the date break in trend growth. The mode for the break in trend growth is estimated to be the second quarter of 2005 with an associated probability of 60%; the remaining 40% probability is spread between 2001 and 2005. Consistent with the timing of breaks in trend growth detected by Eo and Morley (2018), the break in Australia is also estimated to have taken place prior to the global financial crisis of 2008/09.

## 5.2 Estimated transitional dynamics

To assess the quantitative implications of the estimated change in trend growth, $\Delta z$, we compute the transitional dynamics implied by the joint posterior of structural parameters

Figure 5: Cumulative Posterior Distributions of Date Breaks



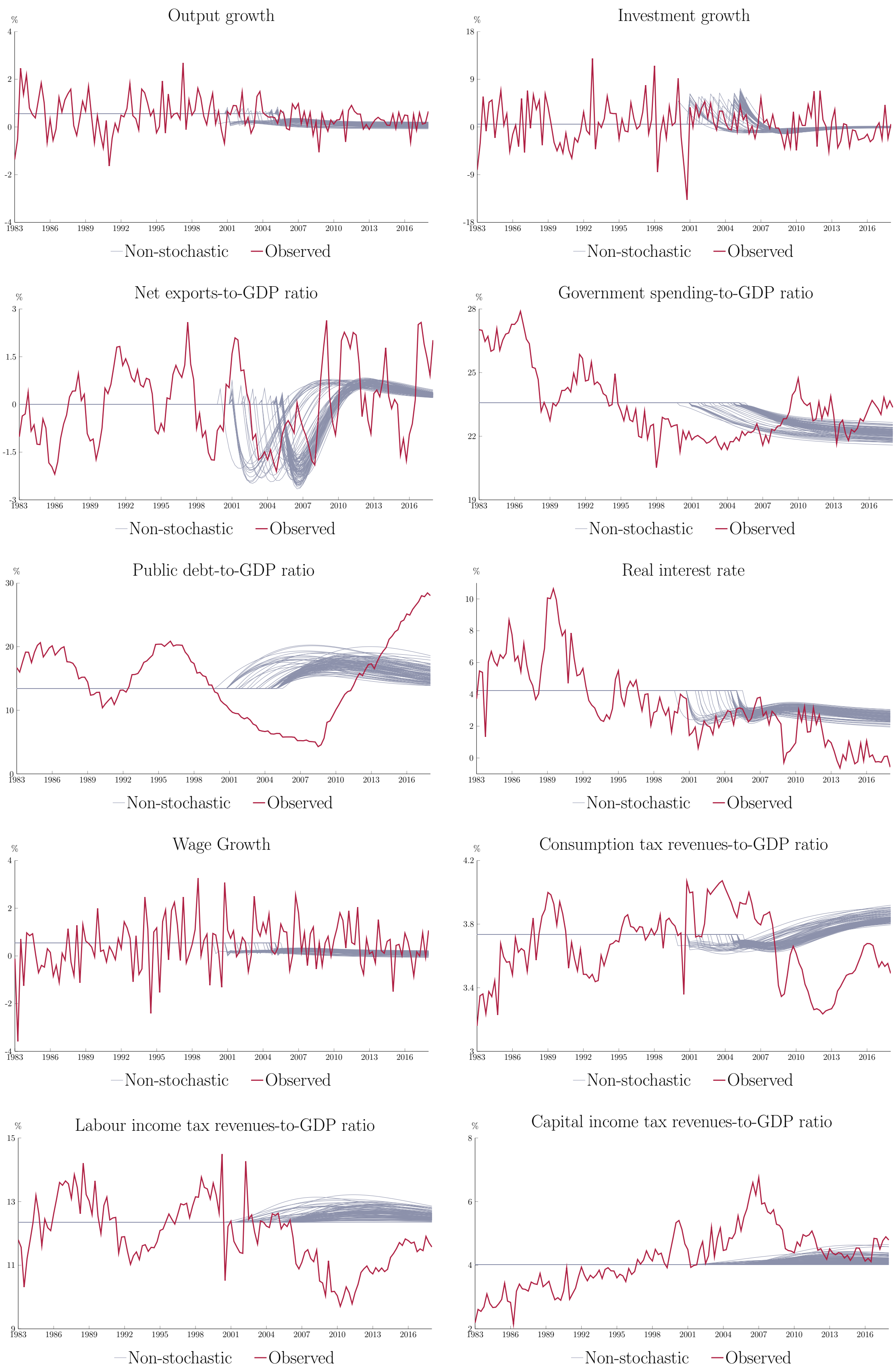

and date breaks. We take 100 draws from the posterior and at each draw compute the non-stochastic transition path: the path that the economy would follow in the absence of structural shocks but in the presence of $\Delta z$.

Figure 6 plots the posterior distribution of the estimated transitional dynamics together with the observable variables used in estimation. Most transition paths start around the second quarter of 2005, the mode of the date break in $z$, although some paths start before then.

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 $\rho_{R^*}$, 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, $R_t > R_t^*$, leads to capital inflows reflected in a deterioration of the trade balance as shown in Figure 6. If the persistence of the foreign real interest rate, $\rho_{R^*}$, were sufficiently higher, it would take longer for $R_t^*$ to adjust and

Figure 6: Data and Estimated Transitional Dynamics



$R_t$ 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.[12]

In the baseline specification, the fiscal authority leaves fiscal policy rules unchanged, in particular $g$ in Equation (16), so the government spending-to-output ratio, $g_t/y_t$, gradually falls. 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 23.5 per cent to the lower value of 22 per cent.

As explained in Section 3, lump-sum transfers adjust to satisfy the government budget constraint in the long-run. Because the consumption share of output increases in the new balanced growth path, the consumption tax revenues share of output increases by 0.2 percentage points. So for the government budget constraint to hold in the long-run, the lump-sum tax share of output must fall by 1.7 percentage points. The speed with which lump-sum taxes adjust towards the new steady state is governed by $\rho_\tau$, which is estimated to be around 0.21. And since the persistence of government spending, $\rho_g$, is significantly higher, 0.95 at the mode, government spending as a share of output takes longer than lump-sum taxes to adjust. And although consumption tax revenues eventually increase, the initial fall in consumption depresses consumption tax revenues. As a result, following the fall in trend growth, the primary deficit expands which contributes to a rise in the government debt-to-output ratio.

Tax rates on capital income, labour income and consumption expenditures subsequently rise in response to rising government debt according to Equations (17) to (19) to restore fiscal balance. The increase in the tax rate on capital income together with the increase of the capital stock fueled by the rise of investment more than offsets the fall in interest rates and so tax revenues from capital income increase as share of output in the transition; eventually, it converges back to $\tau^K\alpha$. The increase in the capital stock increases the marginal product of labour which increases real wages. Hours worked on impact increase as consumption falls and as result tax revenues from labour income also rise as share of output in the transition; eventually, this share converges back to $\tau_w(1-\alpha)$.

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

## 5.3 Variance Decompositions

In our sample, the economy can be in one of four possible regimes. The estimated cumulative distributions functions, however, suggest that the most prevalent are the high trend growth high variance and the low trend growth low variance regimes. Table 4 computes variance decompositions of the two regimes for the observable series used in estimation.

In spite of the estimated regime changes, the contributions of shocks to the variance of the observables is broadly stable across regimes. Productivity and labour supply shocks account for over 80 per cent of the variance of output growth. Fiscal policy shocks, shocks to government spending and tax revenues, however, do not account for the bulk of the fluctuations in output, investment, net exports, wage growth and real interest rates which suggests that fiscal policy is not a significant source of macroeconomic volatility.

## 5.4 Sensitivity Analysis

One may wonder the extent to which the estimate of $\Delta z$ is sensitive to the choice of observable variables. To assess this consider the distance between the observable series and their estimated transitional dynamics; this distance is due to structural shocks. As can be seen in Figure 6, some observable series are close to their estimated transitional dynamics which implies that smaller shocks are required to fit these observables. This observation points to which observables may be relevant for identifying $\Delta z$. But this observation also suggests that an estimation that fails to account for a break in $z$ will fit these data worse. In fact, we have estimated the model without breaks and found that the log marginal density falls from 4703.3 to 4632.8 which is evidence in favour of a specification that allows for a permanent change in trend growth.

To study the sensitivity of the estimate of $\Delta z$ to the choice of observables, we first estimate an unobserved components model on the GDP per capita series alone, allowing for a change in trend growth and a change in the variance of shocks as we did with the structural model. In the interest of space, the details of this exercise are relegated to appendix C, but 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 2007-Q4. The timing of the break in $z$ is relatively close to what was obtained with the structural model. But, although the posterior distributions of $\Delta z$ overlap to some extent, the estimate of $z'$ is significantly higher in the unobserved components model than the estimate of $z'$ in the structural model of 0.16% per year. We also cast the unobserved components model in growth terms and estimate the first-

Table 4: Variance Decompositions

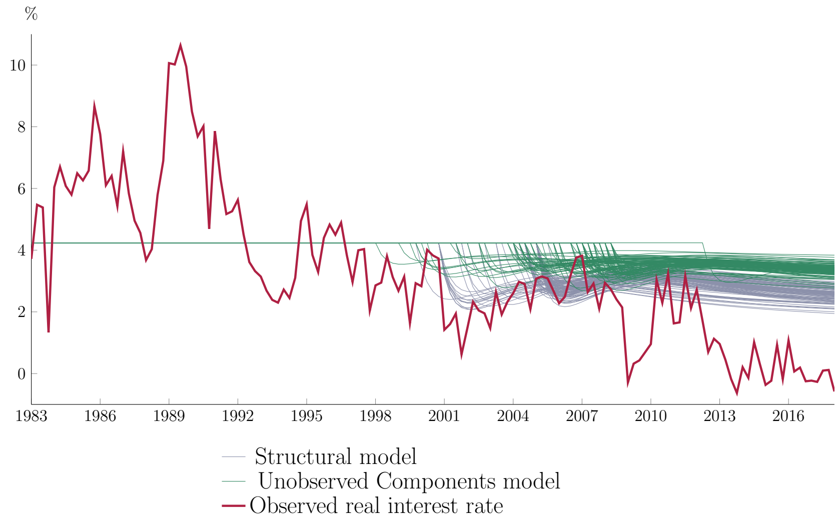
| Variable | Shock | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $\varepsilon_z$ | $\varepsilon_{R^*}$ | $\varepsilon_\zeta$ | $\varepsilon_L$ | $\varepsilon_I$ | $\varepsilon_g$ | $\varepsilon_c$ | $\varepsilon_w$ | $\varepsilon_K$ | $\varepsilon_\tau$ |
| **Initial Regime** | | | | | | | | | | |
| Output growth | 44.3 | 2.7 | 4.8 | 41.0 | 0.9 | 1.4 | 0.0 | 4.8 | 0.1 | 0.0 |
| Investment growth | 6.4 | 0.9 | 8.2 | 3.9 | 78.1 | 0.8 | 0.0 | 0.2 | 1.5 | 0.0 |
| Net exports/GDP | 5.8 | 15.6 | 29.4 | 5.1 | 33.3 | 6.2 | 0.2 | 2.1 | 2.2 | 0.0 |
| Wage growth | 81.7 | 0.8 | 2.1 | 12.6 | 0.8 | 0.4 | 0.0 | 1.5 | 0.1 | 0.0 |
| Real interest rate | 3.7 | 71.8 | 18.3 | 2.3 | 1.9 | 1.3 | 0.0 | 0.2 | 0.5 | 0.0 |
| Government spending/GDP | 0.4 | 0.0 | 1.8 | 77.7 | 0.1 | 19.8 | 0.0 | 0.1 | 0.0 | 0.0 |
| Public debt/GDP | 0.2 | 0.0 | 1.6 | 77.6 | 0.0 | 14.3 | 0.1 | 2.0 | 1.9 | 2.3 |
| Consumption tax revenues/GDP | 4.4 | 0.8 | 15.9 | 35.9 | 0.5 | 4.6 | 37.1 | 0.2 | 0.4 | 0.1 |
| Labour income tax revenues/GDP | 0.1 | 0.0 | 1.0 | 52.2 | 0.0 | 8.9 | 0.0 | 35.3 | 1.2 | 1.2 |
| Capital income tax revenues/GDP | 0.0 | 0.0 | 0.2 | 10.3 | 0.0 | 1.6 | 0.0 | 0.2 | 87.4 | 0.2 |
| **Final Regime** | | | | | | | | | | |
| Output growth | 43.8 | 2.6 | 5.4 | 41.7 | 0.6 | 1.0 | 0.0 | 4.8 | 0.0 | 0.0 |
| Investment growth | 6.2 | 0.8 | 11.6 | 4.0 | 75.0 | 0.9 | 0.0 | 0.2 | 1.2 | 0.0 |
| Net exports-to-GDP | 4.7 | 15.9 | 35.1 | 5.1 | 29.4 | 5.7 | 0.3 | 2.2 | 1.5 | 0.0 |
| Wage growth | 81.3 | 0.8 | 2.4 | 13.1 | 0.5 | 0.3 | 0.0 | 1.5 | 0.0 | 0.0 |
| Real interest rate | 3.5 | 74.0 | 16.7 | 2.2 | 2.0 | 1.0 | 0.0 | 0.2 | 0.3 | 0.0 |
| Government spending/GDP | 0.5 | 0.0 | 2.1 | 77.7 | 0.1 | 19.5 | 0.0 | 0.1 | 0.0 | 0.0 |
| Public debt/GDP | 0.3 | 0.0 | 1.8 | 80.0 | 0.0 | 12.1 | 0.1 | 1.9 | 1.9 | 1.9 |
| Consumption tax revenues/GDP | 5.7 | 0.8 | 21.9 | 27.8 | 0.5 | 3.5 | 39.1 | 0.2 | 0.3 | 0.1 |
| Labour income tax revenues/GDP | 0.2 | 0.0 | 1.3 | 55.6 | 0.0 | 7.8 | 0.0 | 32.9 | 1.2 | 1.0 |
| Capital income tax revenues/GDP | 0.0 | 0.0 | 0.3 | 11.6 | 0.0 | 1.5 | 0.0 | 0.2 | 86.2 | 0.2 |

**Note:** The variance shares are reported in per cent.

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.

In a series of estimations, we then remove one observable series at a time to assess how the mode of $z' = z + \Delta z$ changes. Consistent with Figure 6, the government spending-to-output ratio, net exports-to-GDP and the real interest rate all contribute to a lower estimate of $z'$. In particular, when the real interest rate is removed from the list of observables, we find the estimate of trend growth rises from 0.16% to 0.31% in the final regime; when the government spending-to-output ratio is removed, the estimate of trend growth rises to 0.41%; and when the net exports to GDP series is removed, the estimate of trend growth increases to 0.65%. Figure 7 compares transitional dynamics of the real

Figure 7: Estimated Transitional Dynamics:
Real Interest Rate




Sources: Authors' calculations; RBA

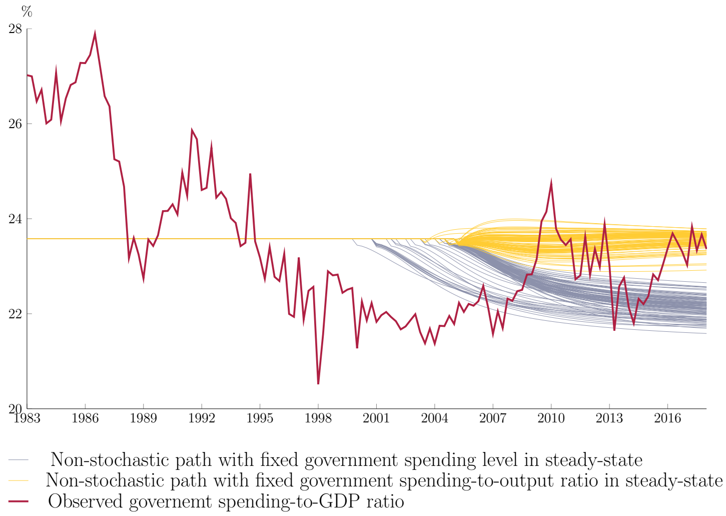
interest rate implied by the posterior distribution from the unobserved components model with the posterior distribution from the structural model. As can be seen in the figure, the lower estimate of $\Delta z$ helps the structural model fit the real interest rate series significantly better.

To assess the sensitivity of our estimates to assumptions about fiscal policy in the presence of a permanent change in trend growth, we estimate the specification in which the fiscal authority updates $g$ in Equation (16) when the change in $z$ happens so that the size of government, $g/y$, in the final regime is the same as in the initial one. Under this alternative specification for fiscal policy, trend growth in the final regime is estimated to be 0.59% per year. This estimate is considerably closer to the unobserved components model, but the log marginal density falls to 4691.6 which implies that this specification provides does not fit the data as well. Figure 8 compares the estimated transitional dynamics in the two cases. As the figure shows, the case in which the government spending-to-output ratio is the same in the final regime requires larger shocks to account for the deviations from the estimated transitional dynamics in sample, in particular throughout the late 1990s and the 2000's.

## 5.5 Counterfactual Analysis

Finally, we use the estimated model to perform some counterfactual calculates. In particular, we are interested to assess how the economy would have evolved in the absence

Figure 8: Estimated Transitional Dynamics:
Government spending-to-GDP ratio



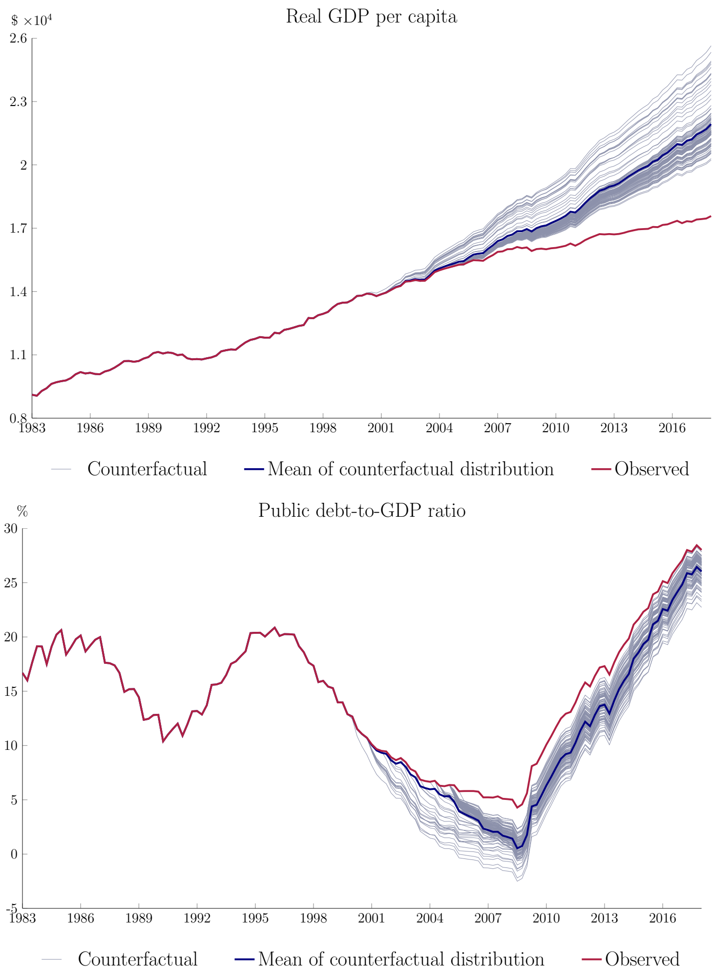

Sources: ABS; AOFM; Authors' calculations

of slowdown in trend growth. We draw from the posterior and at each draw compute the smoothed structural shocks. We then use these shocks to compute what the evolution of the economy would have been under the assumption that $\Delta z = 0$, that is assuming there was no reduction in trend growth.

Figure 9 plots the posterior distribution of counterfactual paths for the level of output per capita and for the public debt-to-output ratio. At the end of our sample, by 2018:Q1 actual output per capita is $\$17,574$. At the mean of the posterior distribution of the counterfactual paths, by 2018:Q1, output per capita would have been 25% higher, around $\$21,930$. The cumulative loss of output over the whole sample at the mean is estimated to be $\$103,528$, equivalent to one and a half times annual GDP per capita.

The differences in the evolution of the public debt-to-output ratio are, however, less staggering. As we argued above, the slowdown in trend growth increases the debt-to-output ratio given the fall in tax revenue. The fall in the government spending-to-output ratio, however, offsets some of this effect. From the estimated transitional dynamics we see that the debt to annual output ratio increases on average by around 4 percentage points at the peak of the transition. Towards the end of the sample we find that in the absence of a change in trend growth, the debt-to-output ratio would have been only around 2 percentage points lower.

Figure 9: Counterfactual Paths of Observable Variables in Absence of Trend Growth Slowdown




Sources: ABS; Authors' calculations

# 6 Conclusion

It seems increasingly evident that trend growth around the world has slowed down. In this paper, we set up a small open economy model to estimate the magnitude of the slowdown and assess what some of the fiscal implications are.

We find strong evidence in favour of a permanent slowdown in trend growth with a structural model under different specifications of fiscal policy; we also find strong evidence using a statistical unobserved components model. This result is consistent with findings in the literature. But the estimation with the structural model points to a more pronounced slowdown than what a statistical model suggests. With the help of estimated transitional dynamics, we examine why this is the case: the real interest rate, the trade balance, and the behaviour of the government spending-to-output ratio all suggest that the slowdown is more pronounced than is implied by the GDP per capita series alone. This is because a more pronounced slowdown fits these data series better. Our inferences of trend growth rely on many observables that in general equilibrium also respond to a permanent change in trend growth. The additional information in these series suggest that trend growth in per capita output is quite low.

The hypothesis that there is a constant government spending-to-output ratio across different balanced growth paths has little support in the data. The alternative hypothesis where the government spending-to-output ratio shrinks over the sample fits the data better. This raises the issue of how one should model fiscal policy when the balanced growth path changes, in particular how the government budget constraint is assumed to be satisfied in the long-run.

There are questions that we leave for future research. We have also assumed that lump-sum transfers adjust to the slowdown in trend growth, implying that the government does not respond by adjusting labour, capital or consumption tax rates. We have considered a model in which government debt is real, in which there is no government investment and for which government spending is wasteful. Our analysis considers estimated fiscal rules but abstracts from optimal fiscal policy considerations. Studying how changes in trend growth affects fiscal policy in a model that relaxes any or all of these assumptions are worthwhile avenues for further research.

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# A Data Sources

This section describes the data used to estimate the model.

- **Population:** Quarterly gross domestic product in chain volume measure (ABS Catalogue 5206.001) divided by quarterly gross domestic product per capita also in chain volume measure (ABS Catalogue 5206.001).

- **Real GDP per capita:** Quarterly gross domestic product per capita in chain volume measure (ABS Catalogue 5206.001). This series enters in first difference in the estimation.

- **Investment per capita:** Quarterly gross fixed capital formation in chain volume measure (ABS Catalogue 5206.002) divided by population. This series enters in first difference in the estimation with its sample mean adjusted to match the sample mean of real output growth.

- **Government spending-to-GDP ratio:** Quarterly government consumption and pubic gross fixed capital formation in current prices (ABS Catalogue 5206.003) divided by quarterly gross domestic product in current prices (ABS Catalogue 5206.003). This series enters in log form in the estimation.

- **Net exports-to-GDP ratio:** Net exports-to-GDP is computed as exports-to-GDP less imports-to-GDP. Exports-to-GDP is quarterly exports in current price measure divided by quarterly gross domestic product in current prices. Imports to-GDP is quarterly imports in current prices divided by quarterly gross domestic product in current prices (ABS Catalogue 5206.003). The sample mean of this series is removed prior to the estimation.

- **Hourly wage:** Compensation of employees (ABS Cat 5206.044) divided by the hours worked index (ABS Cat 5206.001). The series is deflated by the consumption deflator (ABS Cat 5206.005). This series enters in first difference with its sample mean adjusted to equal the mean of output growth.

- **Real interest rate:** 90-day bank bill rate (RBA Bulletin Table F1). This nominal interest rate is converted to a real rate using the trimmed mean inflation series (RBA Bulletin Table G1). The monthly series is converted into quarterly frequency by arithmetic averaging.

- **Public debt-to-GDP-ratio:** Commonwealth government securities on issue (Australian Office of Financial Management and RBA Bulletin Table E3) divided by quarterly gross domestic product in current prices (ABS Catalogue 5206.003).

- **Consumption tax revenues-to-GDP-ratio:** The sum of sales tax revenues and goods and services tax revenues in current prices (ABS Cat 5206.022) divided by quarterly gross domestic product in current prices (ABS Catalogue 5206.003). The mean of the series is adjusted for the subsample 1983-2000 to adjust for the break resulting from the introduction of the goods and services tax in the year 2000.

- **Labour income tax revenues-to-GDP ratio:** Individual income tax revenues in current prices (ABS Cat 5206.022) divided by quarterly gross domestic product in current prices (ABS Catalogue 5206.003).

- **Capital income tax revenues-to-GDP ratio:** The sum of resident corporations' income tax revenues and non-residents' income tax revenues in current prices (ABS Cat 5206.022) divided by quarterly gross domestic product in current prices (ABS Catalogue 5206.003)

# B Growth Accounting Calculations for Australia

To perform the growth accounting exercise, we assume Australia's output per capita can be modelled as a Cobb-Douglas aggregate of available technology and capital per capita:

$$y_t = A_t k_t^\alpha \tag{28}$$

where $y_t$ is output per capita, $A_t$ is total factor productivity, and $k_t$ is capital per capita. Hence, output per capita growth, $g_y$, is given as:

$$g_y = g_a + \alpha g_k \tag{29}$$

where $g_a$ is the contribution of total factor productivity to output per capita growth and $\alpha g_k$ is the contribution of capital per capita of output growth. The results of the growth accounting calculations for Australia are given in Table 5.

Table 5: Growth Accounting Calculations for Australia

| Period | Average GDP per capita growth % | Contribution of capital per capita % | Contribution of total factor productivity % |
|---|---|---|---|
| 1990-2000 | 2.02 | 0.61 | 1.41 |
| 1990-2017 | 1.65 | 0.70 | 0.95 |
| 2000-2017 | 1.36 | 0.77 | 0.59 |
| 2010-2017 | 1.10 | 0.70 | 0.40 |

Below is a description of the data used in the growth accounting calculation:

- **Population:** Annual gross domestic product in chain volume measure (ABS Catalogue 5204.0) divided by annual gross domestic product per capita also in chain volume measure (ABS Catalogue 5204.0).
- **Real GDP per capita:** Gross domestic product using the production based approach in chain volume measure (ABS Catalogue 5204.0) divided by population.
- **Capital per capita:** End-year net capital stock in chain volume measure (ABS catalogue 5204.0) divided by population.
- **Capital share in production function:** The ratio of gross operating surplus in all sectors to income. Income is computed as the sum of compensation of employees (ABS Catalogue 5204.0) and gross operating surplus in all sectors (ABS Catalogue 5204.0).

# C Unobserved Components Estimates

We set up an unobserved components trend-cycle decomposition model for the quarterly level of GDP and allow for a break in output trend to happen at any date as well as a break in the variance of the shock to the trend and variance of the shock to the cycle to occur on the same date. The unobserved components trend-cycle decomposition model is given by:

$$y_t = \tau_t + c_t \tag{30}$$

$$\tau_t = z\mathbf{1}(t < T_z) + (z + \Delta z)\mathbf{1}(t \geq T_z) + \tau_{t-1} + \epsilon_t^\tau \tag{31}$$

$$c_t = \rho_1 c_{t-1} + \rho_2 c_{t-2} + \epsilon_t^c \tag{32}$$

where $y_t$ is the logarithm of Australia's real GDP per capita which is decomposed into a trend component $\tau_t$ and a cyclical component $c_t$. The trend component $\tau_t$ is specified as a random walk with a drift and we allow for a break in the drift to happen at the date $T_z$. $\mathbf{1}(A)$ is an indicator function that takes the value 1 if the condition $A$ is true and a value of 0 otherwise. As such, the mean growth rate of the trend equals $z$ before the break date $T_z$, and $z' = z + \Delta z$ on and after the break date. The cyclical component $c_t$ is modelled as a zero-mean stationary AR(2) process. We assume that the innovations $\epsilon_t^\tau$ and $\epsilon_t^c$ are independently normal:

$$\begin{pmatrix} \epsilon_t^\tau \\ \epsilon_t^c \end{pmatrix} = \mathcal{N}\left(\mathbf{0}, \begin{bmatrix} \mu\sigma_\tau^2\mathbf{1}(t < T_\sigma) + \sigma_\tau^2\mathbf{1}(t \geq T_\sigma) & 0 \\ 0 & \mu\sigma_c^2\mathbf{1}(t < T_\sigma) + \sigma_c^2\mathbf{1}(t \geq T_\sigma) \end{bmatrix}\right)$$

We allow for a break in the variances of the innovations $\epsilon_t^\tau$ and $\epsilon_t^c$ to occur at the same date $T_\sigma$. As such, the variances of the shocks to the trend and the cycle are respectively $\mu\sigma_\tau^2$ and $\mu\sigma_c^2$ before the break date $T_\sigma$, and $\sigma_\tau^2$ and $\sigma_c^2$ on and after the break date.

The unobserved components trend-cycle decomposition model can be written is state space form:

$$y_t = \begin{bmatrix} 1 & 1 & 0 \end{bmatrix} x_t \tag{33}$$

$$x_t = \begin{bmatrix} z \\ 0 \\ 0 \end{bmatrix} \mathbf{1}(t < T_z) + \begin{bmatrix} z' \\ 0 \\ 0 \end{bmatrix} \mathbf{1}(t \geq T_z) + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \rho_1 & \rho_2 \\ 0 & 1 & 0 \end{bmatrix} x_{t-1} + \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \epsilon_t^\tau \\ \epsilon_t^c \end{bmatrix} \tag{34}$$

where $x_t = \begin{bmatrix} \tau_t & c_t & c_{t-1} \end{bmatrix}'$.

To estimate the model, we calibrate the growth rate in the initial regime at 0.0055 as in the small open economy model and use a Bayesian estimation technique to estimate the remaining parameters ($\vartheta$) and the break dates ($\mathbf{T}$). We set the priors to either be in consistence with the literature or to be uninformative. Uniform prior with support 0 to 0.015 is set for the mean growth of the trend parameter $z'$ . Normal distribution with mean 0.9 and standard deviation 1 is imposed on the autoregressive parameter $\rho_1$. For the autoregressive parameter $\rho_2$, we impose a normal prior with mean 0 and standard deviation 1. The priors on the standard deviations of shocks, $\sigma_\tau$ and $\sigma_c$ are set as uniform priors with support 0 and 0.2. Further, a uniform prior $[0, 3]$ is imposed on the variance scale parameter $\mu$. Finally, flat priors are imposed for the break date $T_z$ and $T_\sigma$ and the initial regime is restricted to be at least 60 quarters long. The prior and posterior distributions of the parameters from estimating the model at level and at first-difference are listed in Tables 6 and 7, respectively.

Table 6: Prior and Posterior Distribution of the Parameters and Break Dates from Level Estimation

| | Prior distribution | | | Posterior distribution | | | |
|---|---|---|---|---|---|---|---|
| Parameter | Dist. | Mean | S.d. | Mean | Mode | 5% | 95% |
| **Parameters** | | | | | | | |
| $z'$ | Uniform | $[0, 0.015]$ | | 0.0025 | 0.0029 | 0.0015 | 0.0035 |
| $\rho_1$ | Normal | 0.9 | 1 | 0.8983 | 0.9407 | 0.7791 | 0.9836 |
| $\rho_2$ | Normal | 0 | 1 | 0.0098 | 0.0588 | -0.0120 | 0.0391 |
| $\sigma_\tau$ | Uniform | $[0, 0.2]$ | | 0.0057 | 0.0079 | 0.0007 | 0.0090 |
| $\sigma_c$ | Uniform | $[0, 0.2]$ | | 0.0049 | 0.0007 | 0.0005 | 0.0087 |
| $\mu$ | Uniform | $[0, 3]$ | | 2.0130 | 1.8528 | 1.6134 | 2.4782 |
| $T_z$ | Flat | [1997:Q4, 2015:Q2] | | 2006:Q3 | 2007:Q4 | 2002:Q3 | 2008:Q3 |
| $T_\sigma$ | Flat | [1997:Q4, 2015:Q2] | | 2002:Q1 | 2004:Q1 | 1998:Q2 | 2005:Q2 |

Table 7: Prior and Posterior Distribution of the Parameters and Break Dates from First-Difference Estimation

| | Prior distribution | | | Posterior distribution | | | |
|---|---|---|---|---|---|---|---|
| Parameter | Dist. | Mean | S.d. | Mean | Mode | 5% | 95% |
| **Parameters** | | | | | | | |
| $z'$ | Uniform | $[0, 0.015]$ | | 0.0025 | 0.0030 | 0.0014 | 0.0036 |
| $\rho_1$ | Normal | 0.9 | 1 | 0.8306 | 0.9619 | 0.1374 | 1.4588 |
| $\rho_2$ | Normal | 0 | 1 | -0.2277 | 0.0000 | -0.8021 | 0.4099 |
| $\sigma_\tau$ | Uniform | $[0, 0.2]$ | | 0.0075 | 0.0001 | 0.0037 | 0.0094 |
| $\sigma_c$ | Uniform | $[0, 0.2]$ | | 0.0025 | 0.0078 | 0.0002 | 0.0073 |
| $\mu$ | Uniform | $[0, 3]$ | | 1.9919 | 1.8421 | 1.5999 | 2.4404 |
| $T_z$ | Flat | [1997:Q4, 2015:Q2] | | 2006:Q3 | 2007:Q4 | 2002:Q1 | 2008:Q3 |
| $T_\sigma$ | Flat | [1997:Q4, 2015:Q2] | | 2001:Q4 | 2001:Q1 | 1998:Q1 | 2005:Q1 |