ESTIMATING TRENDS IN AUSTRALIA'S PRODUCTIVITY

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Treasury Working Paper

2009 — 01

February 2009

Earlier versions of this paper were presented at the 11th Australasian Macroeconomic Workshop and the 35th Australian Conference of Economists in 2006. The authors are, or were, from the Macroeconomic Group of the Australian Treasury. The authors would like to thank Jason Allford, Graeme Davis, Ben Dolman, David Gruen, Paul O'Mara, Tony McDonald, John Simon, and Jim Thomson for their helpful suggestions. The views in this paper are those of the authors and not necessarily those of the Treasury.

ABSTRACT

Productivity trends greatly influence the future size of an economy, its ability to meet the challenges of an ageing population, and the setting of both fiscal and monetary policies. This paper estimates trend growth in productivity (GDP per hour worked) in Australia since the late 1970s. Results suggest that trend productivity growth increased markedly during the 1990s. Since that time, however, trend productivity growth has weakened — our estimates suggest that productivity has grown at an annual average trend rate of between 1.5 and 1.8 per cent since the economic slowdown in 2000.

JEL Classification Numbers: E66, 047

Keywords: Trend productivity growth.

CONTENTS

1. INTRODUCTION

Growth in productivity (output produced per hour worked) is the main source of improvements in living standards in the long run. Assumptions about productivity growth are crucial for macroeconomic stabilisation policy and in projecting the future size of an economy and a country's ability to meet future fiscal pressures from demographic changes. For example, were faster productivity growth to be realised, the resulting increase in taxation revenue flowing from the larger economy would more than eliminate the component of the Intergenerational Report fiscal gap that arises from the ageing of the population, other factors unchanged (Gruen and Garbutt, 2004).

This paper presents a number of estimates of Australia's trend productivity growth. The aim is to investigate whether the observed strong productivity growth of the late 1990s, and its subsequent weakening, was due to changes in trend productivity growth. Alternatively, did cyclical factors result in the measured changes in productivity growth?

The results suggest that trend productivity growth rose markedly during the 1990s — particularly, it was much stronger during the late 1990s than was the case earlier. Further, trend productivity growth appears to have weakened since the beginning of this decade.

The rest of the paper is organised as follows: Section 2 provides the motivation; Section 3 describes methodologies and discusses the data; Section 4 presents the results; and Section 5 concludes. Throughout the paper, productivity is used synonymously with labour productivity, and the annual average growth of 1¾ per cent is considered as a benchmark growth rate for productivity.

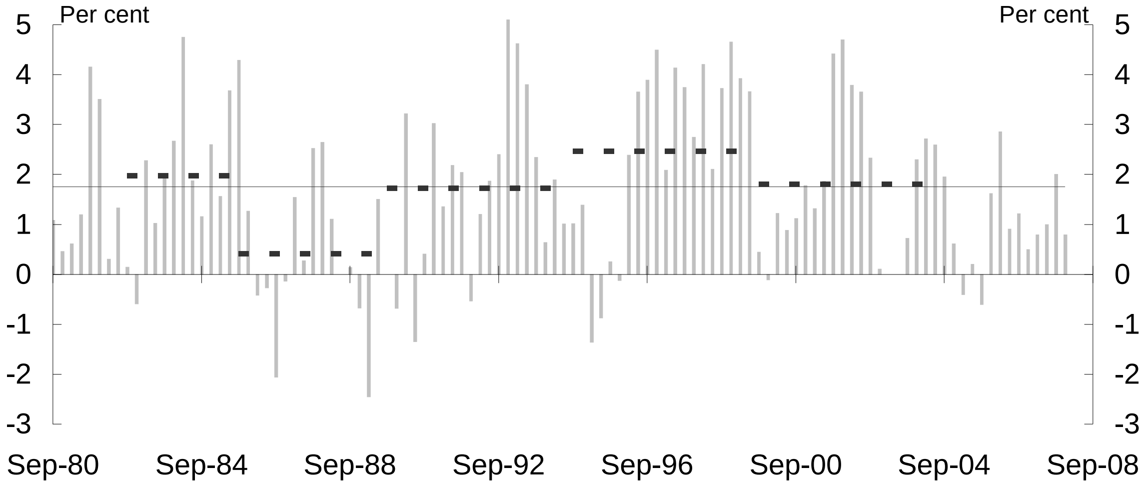
2. MOTIVATION

The analysis of productivity growth is difficult because of significant short-term fluctuations. As a result, average rates of growth over a number of years provide a better indication of trend productivity than the growth rate in a single year. However, productivity growth varies over the business cycle. Therefore, some care is required in choosing the periods over which to average productivity growth — comparing the average rate of growth in a period that includes two years of weak growth with a period that includes none will give a misleading impression of trend productivity.

The Australian Bureau of Statistics (ABS) attempts to allow for these cyclical fluctuations by averaging rates of growth across identified 'productivity growth cycles'. The cycles are defined as the periods between two 'productivity peaks', where the peaks are the points of local maximum above a smoothed (Henderson 11-period moving average) series of multi-factor productivity in the market sector (ABS, 2005). In practice, these cycles are constructed so that there is only one weak period, usually early, in each cycle.

Chart 1 shows average productivity growth over the ABS-defined productivity growth cycles. While productivity grew at a faster pace during the late 1990s (five years to 1998-99) than the Benchmark of 1¾ per cent, productivity growth moderated towards that rate in the most recent completed productivity growth cycle (five years to 2003-04).

Chart 1: Productivity growth cycles

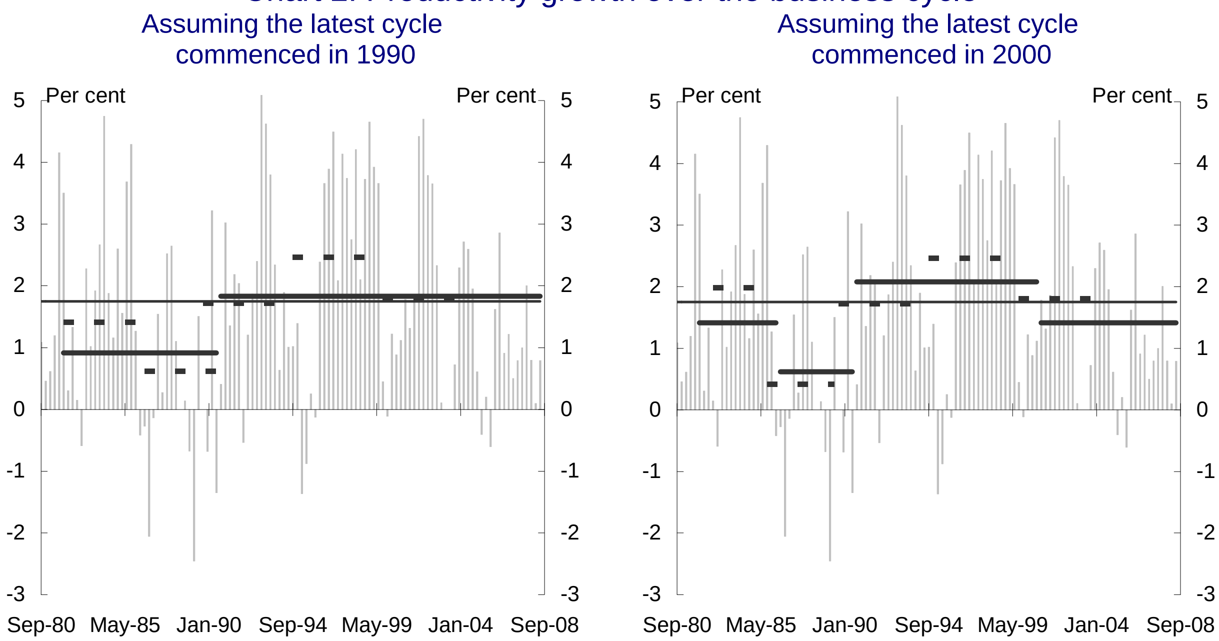


The columns represent actual through-the-year growth; the broken lines represent annual average growth over the productivity growth cycles; and the thin line represents the benchmark.
Source: ABS National Accounts.

There are a number of economic reasons why productivity exhibits cyclical patterns (Basu and Fernald, 2000). The intensity with which labour and capital are used varies over the business cycle. Firms may choose to retain staff during economic downturns to avoid re-hiring costs and the loss of firm-specific skills even though there may not be sufficient demand for final products to keep staff working at peak capacity. A different argument is that production technology fluctuates and these fluctuations are an important driver of the broader business cycle. These reasons suggest that average productivity growth over the business cycle might be a better indicator of the underlying trend in the productivity growth rate.

One mechanical way of removing cyclical fluctuations from the data is to average rates of productivity growth between two recessions, where a recession is defined as two consecutive quarters of falling GDP. However, not all business cycles end in recessions — some business cycles end in downturns that do not lead to a recession. This might have been the case in 1986 and 2000 (Ewing and Hawkins, 2006). Such downturns could nonetheless affect underlying productivity trends. Chart 2 compares average productivity growth over different definitions of the business cycle with the productivity growth cycle.

Chart 2: Productivity growth over the business cycle



The columns represent through-the-year growth; the solid lines represent annual average growth rates over the business cycle; the broken lines represent annual average growth over the productivity growth cycles; and the thin line represents the benchmark.
Source: ABS National Accounts.

Consider productivity growth between recessions first. Productivity has grown by an annual average rate of 1.7 per cent since the June quarter of 1990 — the GDP peak before the last recession. This is faster than what was achieved between the earlier recessions for which quarterly data are available. However, this is barely different from the average over the latest productivity growth cycle (1998-99 to 2003-04). That is, the period of strong productivity growth in the late 1990s disappears once the entire period since the last recession is considered.

A different picture is painted by productivity growth between downturns. Productivity grew by an annual average of 2.1 per cent between the early 1990s recession and the 2000 downturn. This rate is much stronger than the benchmark, albeit not quite as strong as that achieved during the late 1990s productivity growth cycle. However, annual productivity growth has averaged only 1.4 per cent since the September quarter 2000, the GDP peak before that year's downturn.

This raises two questions: was there a pick-up in trend productivity growth in the late 1990s; and, if so, has it continued into the current decade?

A number of conjectures have been made about Australia's recent productivity experience. The opening up of the domestic economy to international trade, adoption of information and communication technologies (ICT), and increased R&D activity might have led to an increase in trend productivity *growth* during the 1990s (Gruen, 2001; Parham, 2004). A similar view is that economic reforms of recent decades helped improve Australia's productivity *level* relative to the global technological frontier, and this improvement manifest itself as an increase in the trend productivity growth rate during the 1990s (Dolman, Lu and Rahman, 2006; Davis and Rahman, 2006).

An alternative explanation for the strong observed productivity growth during the late 1990s is that the economy avoided a recession in those years and what is observed as a productivity surge might actually be an unmeasured increase in work hours (Quiggin, 2001).

Turning to the observed weakening in productivity growth during the recent years, Parham (2005) and Ewing et al (2007) argue that a number of one-off short-term factors may have pulled the average down, possibly overstating the measured productivity slowdown.

This paper aims to estimate trend productivity growth by explicitly accounting for the effect of the business cycle. This is done first with state space models that utilise relevant variables to account explicitly for the effects of the business cycle.

We then estimate productivity trends using a Cobb-Douglas production function that accounts for capital deepening.

These estimates allow one to reject at least one of the above conjectures — the evidence suggests that there was a pick-up in the trend productivity growth rate during the late 1990s, rejecting the 'business cycle' conjecture. While trend productivity growth appears to have eased in recent years, supporting the 'level improvement' conjecture, this assessment might change in light of future productivity developments.

3. METHODOLOGY

3.1 Introduction

Australia is not the only country to have experienced a pick up in productivity growth during the 1990s. Productivity in the United States also markedly accelerated in the latter half of that decade. A number of papers try to estimate trend productivity growth in the US after taking that acceleration and the business cycle into account (Gordon, 2003; Kahn and Rich, 2003; Cogley, 2005; French, 2005). The US studies typically attempt to identify trend productivity by using the information in other economic variables, just as econometricians attempt to identify the natural rate of unemployment by relating it to wage and price movements via a Phillips curve.

Gordon (2003) uses state space modelling techniques to estimate trend productivity growth in the US. He compares HP filter estimates of trend productivity with estimates of two state space models, one of which includes a measure of the output gap to control for the business cycle. He finds that trend productivity growth in the US picked up from the mid-1990s onwards.

Kahn and Rich (2003) use growth theory to identify consumption and labour compensation as variables that can help estimate trend productivity growth. They allow for two regimes in productivity growth: high and low. Using a state space model, they find that in the mid-1990s the US economy entered a high-growth regime with a 1.5 percentage points pick up in the annual productivity growth rate. Their technique can also be used to detect changes in trend productivity growth in real time.

French (2005) attempts a related task. Using a hybrid of non-linear regime switching and the Kalman filter, he attempts to determine shifts in trend growth in multi-factor productivity. His technique appears to detect changes in trend productivity growth more quickly and accurately than other methods. However, as Robert Gordon has noted, there is no reason to suppose that productivity growth undergoes abrupt regime shifts.

Cogley (2005) also uses consumption data to explore how fast the US economy might grow. Although he analyses GDP growth, his techniques can be readily extended to productivity growth. Using a Bayesian filtering strategy, he finds that there has been a modest increase in the trend growth rate in the US economy over the past decade. Specifically, GDP per person might be growing more rapidly than during the 1970s, but not as fast as it did in the 1950s and 1960s.

We adopt the Gordon methodology for its ease of implementation using standard statistical packages. The other papers are more advanced extensions of the basic techniques used in Gordon (2003) and might be worth exploring at a later date.

While not explicitly allowing for switching between regimes of high and low productivity growth, the Gordon methodology still allows for a time-varying trend in productivity. Another way to disentangle changes in the trend productivity growth rate from business cycle fluctuations and other similar shocks is to estimate an error-correction equation where productivity growth is corrected for short-term fluctuations by using various explanatory variables. This standard econometric method typically does not allow for a time-varying trend, unless the trend is estimated between some arbitrarily chosen periods (such as the period between two recessions). However, we still estimate such an equation because it allows us to take capital deepening into account explicitly.

3.2 The state space models

The Hodrick-Prescott (HP) filter is perhaps the most commonly adopted detrending technique in macroeconomics. However, this technique is not likely to be useful in answering the questions this paper tries to answer because it does not use any information other than the variable being filtered. State space models allow detrending techniques such as the HP filter to be generalised. Indeed, the HP filter is a special class of state space models (Harvey 1985).

State space models relate signals or observations that are received by measurement instruments to underlying 'state' variables. Harvey (1990, Chapter 3) provides a good introduction to state space models, while a more technical treatment is contained in Hamilton (1994, Chapter 3). These models rely on the Kalman filter, which was described by Casti (2001) as 'probably the single most useful piece of mathematics developed in [the twentieth] century'. The Kalman filter is an algorithm that filters out noise from a system to provide a best guess of the true state of the system. It was most famously used in Apollo 11's onboard computer and is used in almost all modern navigational systems.

In productivity analysis, the Kalman filter uses assumed knowledge of how the economy evolves over time together with last period's best estimate of trend productivity growth to generate a prediction of trend productivity growth. In the current context, however, the emphasis is not on projecting trend productivity, but in understanding past trends. Here, a technique called the Kalman smoother allows the trend productivity growth estimate to be informed by data across the whole sample, which improves the estimate to the extent that future movements in productivity are informative about trend productivity in previous periods.

This paper reports the results of a number of state space models: some estimating the trend productivity level, others the trend productivity growth rate. These models are outlined below.

The first model of the productivity level is the HP filter, which is a special type of state space model called a *smooth trend* model. In this model, the signal equation is:

$$P_t = P^*_t + \varepsilon_t \qquad (1)$$

where P_t is the log of productivity and P_t^* is trend log productivity $\varepsilon_t \sim N\left(0, \sigma_\varepsilon^{\ 2}\right)$ is the error term.

In the state space form, the HP filter has two state equations, one for the level of the trend (2) and one for its slope (3):

$$P^*_t = P^*_{t-1} + \beta_{t-1} \qquad (2)$$

$$\beta_t = \beta_{t-1} + \zeta_t \qquad (3)$$

where $\zeta_t \sim N\left(0, \sigma_\zeta^{\ 2}\right)$ is the error term. The first state equation does not have an error term; the shock to the trend occurs via its growth rate.

This model can be estimated using the Kalman filter as it stands, but the state estimate of the level of the trend may not be very smooth. The HP filter obtains a ‘smooth’ trend by specifying the ratio of the error variances of the state equation (for the slope) and the signal equation. It is standard for quarterly data for this ratio to be set to $\sigma_{\varepsilon}^{2}/\sigma_{\zeta}^{2}=1600$. This ratio is typically denoted as λ.

Following Gordon (2003), univariate state space models can also be used to estimate the trend quarterly productivity growth rate. Let $p_t = P_t - P_{t-1}$ denote the quarterly growth rate in productivity. The first ‘benchmark’ growth model estimates p_t in terms of a time varying parameter, α_t, that follows a random walk. In this model, α_t is interpreted as the trend productivity growth rate.

The following equations describe the system:

$$p_t = \alpha_t + w_t \tag{4}$$

$$\alpha_t = \alpha_{t-1} + v_t \tag{5}$$

where $w_t \sim N\left(0,\sigma_w^{2}\right)$ and $v_t \sim N\left(0,\sigma_v^{2}\right)$ are the error terms.

As in the level models, in estimating this system a smoothness parameter needs to be specified to constrain σ_v^{2}, the variance of the random walk process. Following Gordon (2003), it is assumed that $\sigma_w^{2}/\sigma_v^{2}=32$. This model is dubbed the Gordon filter.

A major caveat to the growth model is that, in assuming trend productivity growth is a random walk, it implies GDP is integrated of order 2, meaning that the growth rate of GDP is a random walk when it is typically assumed to be stationary.

3.3 Augmenting the univariate filters

Because the HP filter assumes that the trend component of the variable concerned is smooth, it might create cyclical components even when there are no cyclical deviations from the trend (which might be the case if the variable follows a random walk). On the other hand, the HP filter might attribute prolonged cyclical patterns to a change in the trend. For example, Gordon (2003) notes that the simple HP filter estimates suggest that the US economic boom of the 1960s was a result of an acceleration in the trend GDP, even though cyclical indicators such as the very low unemployment rate or the very high capacity utilisation rate pointed to an overheating economy.

This means that, for practical purposes, it might be necessary to explicitly account for the business cycle, something simple HP filters cannot do because they use only the variable that is being de-trended. The HP filter is only a statistical model, and, in most cases, richer economic models might provide more insight. Despite its popularity, Pagan (2005) wishes 'death to the HP filter' because of its lack of economics.

Although the HP filter can be estimated without the Kalman filter, casting the HP filter in state space form gives flexibility because explanatory variables can be added to the signal equation. Accordingly, equation (1) is augmented by a number of explanatory variables X_t. The augmented signal equation is thus:

$$P_t = P^*_t + \gamma X_{t-1} + \varepsilon_t \qquad (6)$$

To make it comparable with the simple univariate HP-filter, it is initially assumed that $\sigma_\varepsilon^2 / \sigma_\zeta^2 = 1600$. However, this model uses other explanatory variable, and it is possible to determine the ratio of the variances endogenously such that it maximises the relevant likelihood function (as is done in section 4.2 below).

Similarly, the Gordon filter is augmented by a number of explanatory variables X_t. The following equations describe the augmented growth model:

$$p_t = \alpha_t + \beta X_{t-1} + w_t \qquad (7)$$

$$\alpha_t = \alpha_{t-1} + v_t \quad (8)$$

The models estimating the productivity level use the seasonally adjusted measure. Quarterly growth rates of seasonally adjusted GDP per hour worked are very volatile, however, and initial attempts at estimating the growth models using the seasonally adjusted measure proved futile. Instead, the results reported here use the ABS trend measure of productivity. The ABS Henderson trend measure removes some of the irregular variation in the time series; it is not a measure of the underlying trend productivity that is of interest here.

3.4 Incorporating capital

According to growth theory, along with technological progress capital accumulation is a major source of improvements in output per hour worked that improves the output produced by a given combination of labour and capital inputs. The improvement due to technological progress is called multi-factor productivity (MFP) growth.

The ABS measures multi-factor productivity growth in the market sector of the economy. The market sector includes only those industries in which the volume of output can be measured independently from the inputs into production. For example, the market sector includes industries such as mining and manufacturing, but not government administration.

In the market sector of the economy, the late 1990s pick-up in productivity growth and its subsequent moderation were driven by changes in the multi-factor productivity growth rate while the contribution of capital deepening (increase in the capital-labour ratio) remained broadly constant (Dolman, Lu and Rahman, 2006; Parham, 2004). What happened in the whole economy?

We explore this question by estimating a simple aggregate production function equation for the economy. We assume that in the long run output can be represented by a Cobb-Douglas production function, with constant returns to scale and steady, exponential technological change over time (9).

$$Y_t = AK_t^{\mu} L_t^{1-\mu} e^{\delta t} \qquad (9)$$

Here Y is output, L is labour input, K is capital input, μ is the importance of capital in the production process (and in a competitive economy, it is capital's share of national income) and δ is the exogenous rate of technological change.

In estimation, the assumption of constant returns to scale was tested and accepted by the data. Of course, Cobb-Douglas production functions assume constant capital and labour shares of income, whereas in Australia, capital's share of income has been on the rise in recent years. A more sophisticated production function can better capture this reality better. This is left for future work.

We can rearrange (9) to express productivity ($\Theta = Y/L$) in terms of the capital-labour ratio ($\Gamma = K/L$) and the technology available at a given point in time (10).

$$\Theta_t = A\Gamma_t^{\mu} e^{\delta t} \qquad (10)$$

Taking logs of (10) yields the following linear relationship between the log levels of output, labour, capital and technology (11).

$$P_t = a + \kappa_t + \delta t \qquad (11)$$

As before, P is the log of productivity, and κ is the log of the capital-labour ratio.

We can estimate (11) using quarterly data to decompose productivity growth into multi-factor productivity and the contribution of capital deepening. We derive the capital-labour ratio from the ABS annual index of market sector capital-labour ratio.

3.5 The explanatory variables

The explanatory variables used in regression are: Treasury estimates of the Gruen, Robinson, and Stone (2002) measure of the output gap; the unemployment rate; and the participation rate. All variables are adjusted to be mean zero and lagged one quarter in the augmented HP-filter model. Lagged quarterly changes in the variables are used in the augmented Gordon filter. Data sources are listed in Appendix A.

The output gap variable captures the effect of the business cycle. Since productivity is usually pro-cyclical, one would expect a positive co-efficient on this variable.

The unemployment rate, however, is a counter-cyclical variable. This would suggest a negative co-efficient on this variable. On the other hand, during periods of prolonged falls in unemployment, as has been the case over the past decade (Chart 3), firms might find it harder to employ suitably qualified workers, and this could lead to stagnating productivity. If this effect dominates, the co-efficient on the unemployment rate would be positive.

Chart 3: Unemployment rate

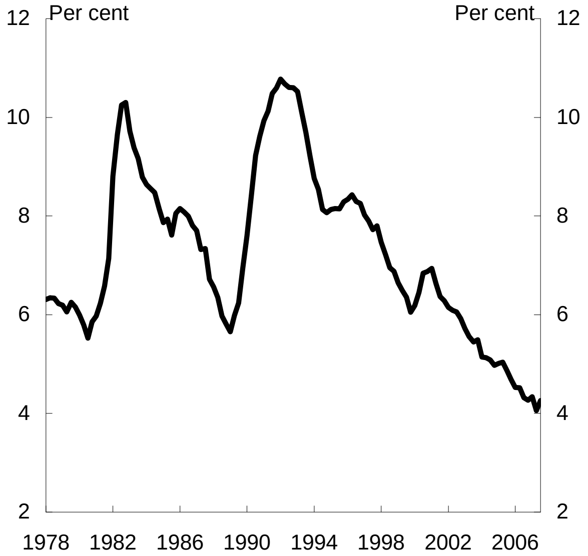
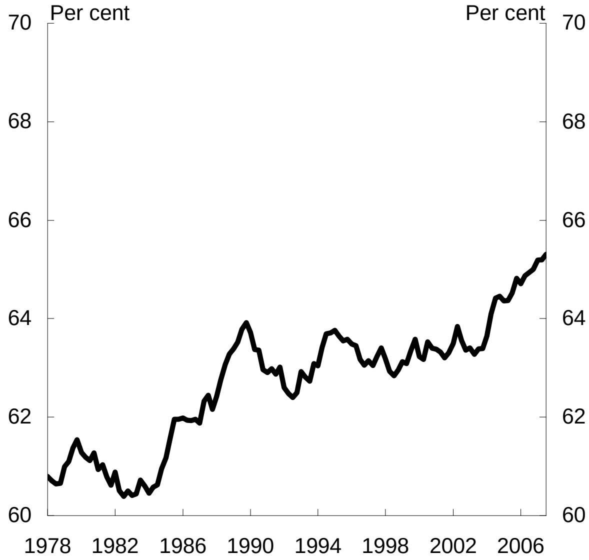


Chart 4: Participation rate



Source: ABS Labour Force Survey.

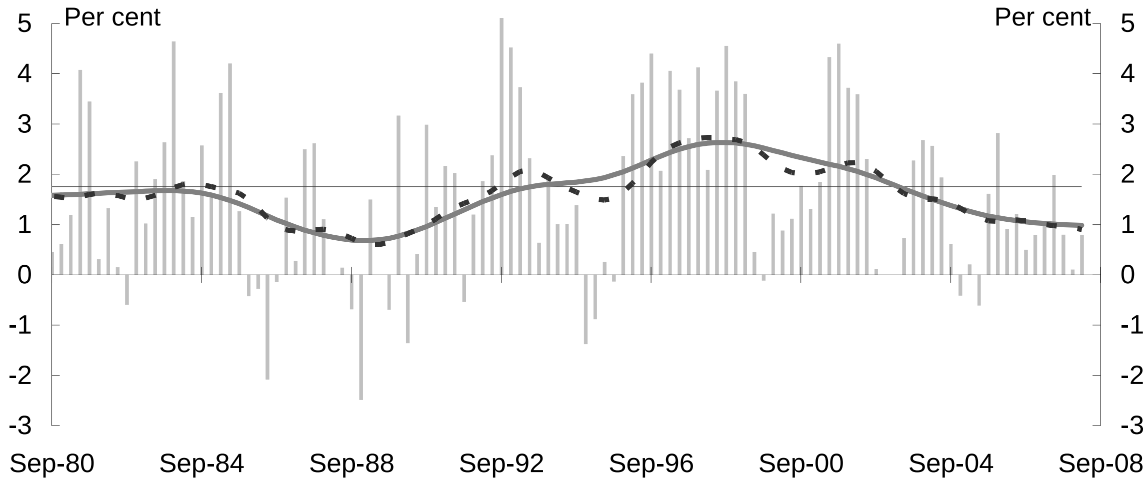
Typically, the participation rate rises during extended periods of economic expansion. Usually such expansions are associated with strong productivity growth, but there are exceptions — the late 1980s is one such period (Chart 4). Further, if the new entrants to the labour force are not as productive as existing workers, a rise in the participation rate would be associated with weaker productivity growth. If this last effect dominates, the co-efficient on the participation rate variable would be negative.

4. Results

4.1 Results of the basic state space models

The primary aim of this exercise is to investigate in more detail the pick up in productivity growth during the late 1990s and its subsequent moderation. As an initial exercise, estimates of trend productivity growth using two univariate filters (Hodrick-Prescott and Gordon) are shown in Chart 5.

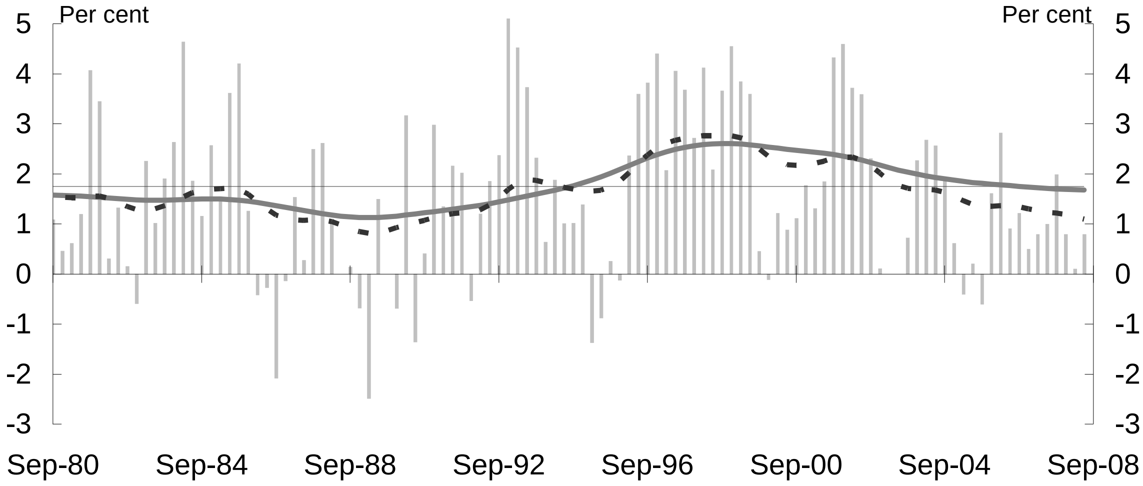
Chart 5: Growth in trend productivity — HP and Gordon filters



The columns represent actual through-the-year growth; the solid line represents through the year growth in trend productivity using the HP filter; the broken line represents through the year growth in trend productivity implied by the Gordon filtered trend productivity growth; and the thin line represents the benchmark.

Trend productivity growth appears to be strong during the 1990s when these filters are used. They also show the subsequent weakening in productivity growth. However, these results are not surprising as these univariate filters do not explicitly account for the business cycle. The effect of the business cycle is then modelled by augmenting these univariate filters with explanatory variables. Chart 6 shows the results.

Chart 6: Growth in trend productivity — the augmented models



The columns represent actual through-the-year growth; the solid line represents through the year growth in trend productivity using the augmented HP filter; the broken line represents through the year growth in trend productivity implied by the augmented Gordon filtered trend productivity growth; and the thin line represents the benchmark.

Both the augmented models show that when we account for the business cycle, the 1990s pick up as well as the subsequent weakening in trend productivity growth remain. Compared with the augmented HP filter, the latest quarters appear quite weak in the augmented Gordon filter. But, as discussed above, the growth model has a major conceptual problem in assuming a random walk in trend productivity growth.

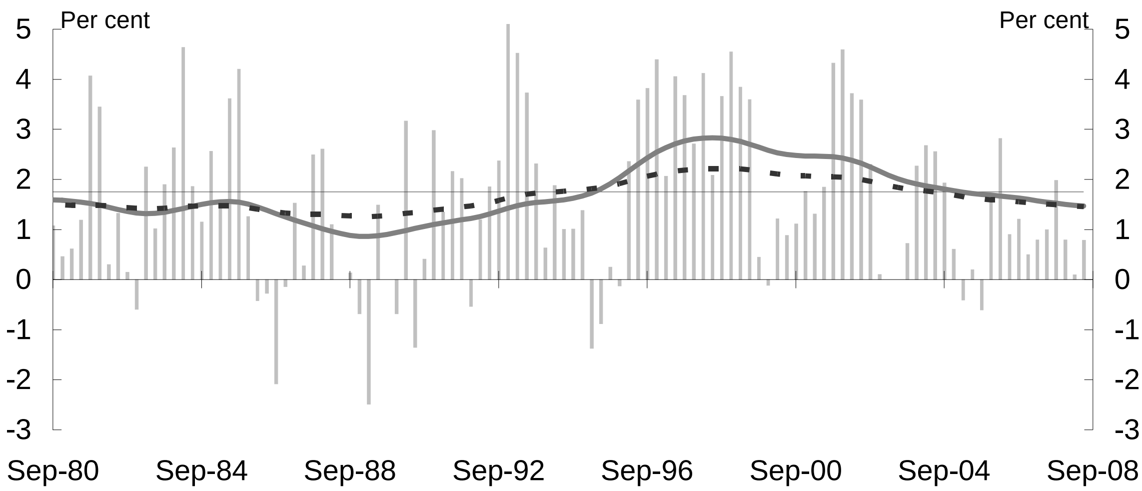
In both models, all explanatory variables are significant at conventional levels despite the likely co-linearity of the output gap and the unemployment rate. As expected, the output gap measure has a positive co-efficient in both models. The unemployment rate measure also has a positive co-efficient, suggesting that the labour quality effect has been more important for productivity growth than the cyclical movements in unemployment. The participation rate has a negative co-efficient, again pointing to the importance of the labour quality effect. A summary of this results are provided in Appendix B. Detailed econometric results are available upon request.

Some extensions to the basic models are presented in the next two sub-sections.

4.2 Unconstrained signal-to-noise ratios

The HP and Gordon filters impose assumed degrees of smoothness on trend productivity. For the HP filter the standard smoothness parameter (signal-to-noise ratio) of 1/1600 was assumed, while for the Gordon filter the assumed signal-to-noise ratio was based on Gordon's judgment. It is possible however to let the signal-to-noise ratios be estimated by the Kalman filter, which provides another set of results (Chart 7).

Chart 7: Growth in trend productivity — the alternative models



The columns represent actual through-the-year growth; the solid line represents through the year growth in trend productivity using the alternative HP filter; the broken line represents through the year growth in trend productivity implied by the alternative Gordon filtered trend productivity growth; and the thin line represents the benchmark.

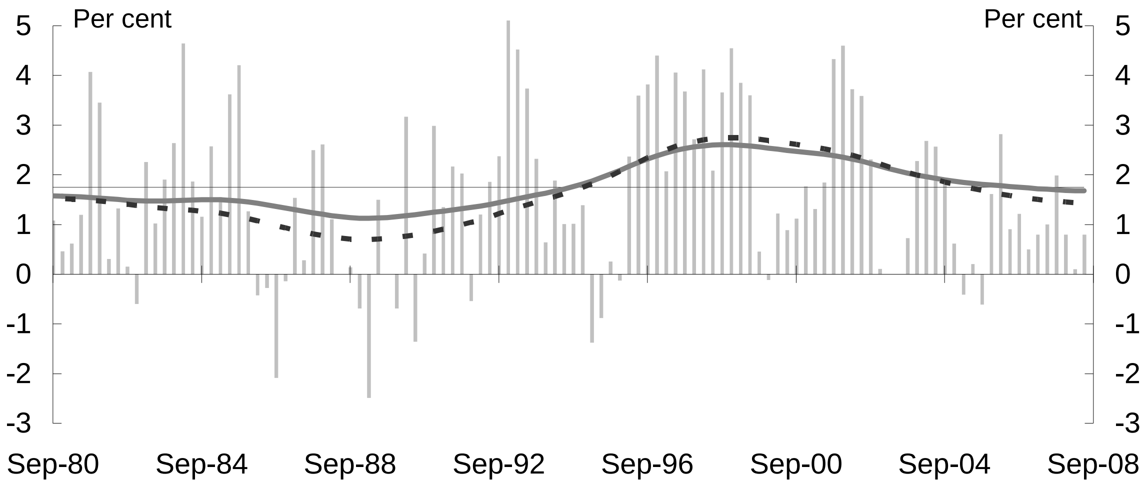
For both the augmented HP and Gordon filters, letting the signal-to-noise ratios be estimated by the Kalman filter confirms the finding that trend productivity increased in the 1990s, and weakened since, even after controlling for the business cycle.

Arguably it is better to let the data speak for themselves than to impose a degree of smoothness on the trend. The implied signal-to-noise ratios were substantially different from the assumed ratios. For the levels model, the implied signal-to-noise ratio was around 1/423 rather than the assumed 1/1600, which would suggest that the augmented HP filter over-smoothed the data. For the growth model, the implied signal-to-noise ratio was 1/202 rather than the assumed 1/32, which would suggest that the augmented Gordon filter under-smoothed the data.

4.3 Non-stationarity in the participation rate

Chart 4 suggests that there might be an upward trend in the participation rate and that it is not stationary around its average value over the sample. Given the concerns about non-stationary variables generating spurious correlations, the augmented HP filter was re-estimated without the participation rate.

Chart 8: Growth in the augmented HP-filtered productivity — effect of the participation rate



The columns represent actual through-the-year growth; the solid line represents through the year growth in the trend productivity using the HP filter augmented with the participation rate; the broken line represents through the year growth in the trend productivity using the HP filter augmented without the participation rate; and the thin line represents the benchmark.

In the re-estimated model the effects of labour market conditions on productivity are only being captured by the unemployment rate. Nonetheless the results suggest that the broad conclusions of the paper remain unchanged (Chart 8).

4.4 Incorporating capital

A Cobb-Douglas production function was estimated using quarterly data to decompose productivity growth into multi-factor productivity and the contribution of capital deepening. To reflect the estimated patterns of trend productivity growth rates, we allow for breaks in the trend rate of technological growth in December 1981, June 1990 and September 2000.

Table 1 decomposes the estimated productivity growth between selected periods in terms of the contribution of capital deepening and technological progress (interpreted as growth in multi-factor productivity in the table).

Table 1: Decomposing medium-term productivity growth

	Capital deepening	Contribution of capital deepening α = 0.31	Multi-factor productivity growth	Labour productivity growth
Sep 1978 to Dec 1981	2.0	0.6	1.0	1.6
Dec 1981 to Jun 1990	2.0	0.6	0.2	0.8
Jun 1990 to Sep 2000	2.5	0.8	1.5	2.2
Since Sep 2000	3.1	1.0	0.7	1.7

The broad conclusions about the 1990s and the current decade remain the same – multi-factor productivity growth registered a marked pick up in the 1990s, and has weakened since.

It turns out that μ_t, the co-efficient on capital deepening, is estimated to be 0.31, implying that around a third of national income accrues to capital. This is close to the stylised coefficient value assumed in the literature (Barro and Sala-I-Martin, 1995, Chapter 1). One must be cautious in interpreting results used in the capital model as to construct a quarterly series we had to interpolate the annual measure. Clearly a more reliable quarterly measure would be better for econometric analysis. This is an important issue for future work.

Productivity and the capital-labour ratio wander over time. Therefore, to maintain the long-run relationship, we would expect any short-term deviations from this relationship to affect the subsequent rate of growth in labour productivity. This suggests estimation of a short-term equation within an error-correction framework for short-term analysis of productivity growth. In addition to estimating (11), we estimated an error correction model of short-term productivity growth – results are similar to Table 1, though recent quarters appear to be weaker than what would be expected from the historical relationship between the variables (details available on request).

4.5 Summary of results

The Kalman-filtered trend estimates are least accurate at the ends of the sample. There is no way of resolving the end-point problem in these models. However, instead of concentrating on the last observation, average growth rates over the latest ongoing business cycle and upturn can be considered (Table 2).

Table 2: Productivity growth in recent years, average per cent per year

	Through the year to June 2008	**September 2000 to June 2008**	**June 1990 to June 2008**
Actual	0.8	1.4	1.7
Trend (by model)			
Augmented HP filter	1.7	1.8	2.0
Augmented Gordon filter	1.1	1.5	1.9
Alternate HP filter	1.5	1.7	2.0
Alternate Gordon filter	1.5	1.6	1.8
Augmented HP filter without participation rate	1.4	1.7	2.0
Production Function Approach	1.7	1.5	2.0

Table 2 suggests that trend productivity is currently around long-term averages, declining from the high growth of the 1990s. Average productivity growth since September 2000 is at or below the long-run average of around 1.75 per cent for all the models.

5. CONCLUSION

This paper reports results that use various techniques to estimate trend growth in productivity in Australia over the past quarter century. Results suggest that trend productivity growth achieved a marked upward shift during the 1990s, but has weakened since then. However, these are preliminary results, and a range of extensions can be made. The effect of capital accumulation on trend productivity growth could be further explored. However, this would require better estimates of capital services growth and perhaps richer model specifications. Also, it is plausible that the links between the labour market variables and productivity are more complicated than the specifications reported in this paper. Economic theory can be used to specify richer dynamics.

Despite the preliminary nature of the results, the estimates in this paper seem reasonable. The surge in trend productivity growth over the late 1990s, while delivering real benefits and permanent increases in living standards, weakened in the current decade. To the extent that the 1990s reflect the benefits of past reforms ongoing reforms that strengthen productivity in areas such as transport, infrastructure and health services have the potential to increase economic growth coupled with low and stable inflation in the medium-term.

APPENDIX A: DATA

Listed below are the data used in this paper. This paper uses June quarter 2008 vintage National Accounts data.

<u>Productivity</u> (ABS National Accounts 5206.1)

GDP per hour worked (Index) — seasonally adjusted for the HP-filter models, trend for the Gordon-filter models.

<u>Output Gap</u>

Derived by the Prices and Wages Team of the Australian Treasury using the Gruen, Robinson and Stone (2002) approach.

<u>Unemployment rate</u> (ABS Labour Force 6202.2)

Seasonally adjusted monthly data from the ABS Labour Force Survey averaged over the quarter.

<u>Participation rate</u> (ABS Labour Force 6202.2)

Seasonally adjusted monthly data from the ABS Labour Force Survey averaged over the quarter.

<u>Capital labour ratio in the market sector — hours worked basis</u> (ABS Australian System of National Accounts 2007-08 5204.14)

Quarterly growth rates interpolated from the annual series.

APPENDIX B: RESULTS

Table 3. HP Productivity Estimation Results

		Gordon Models	
Model	**Original**	**Aug**	**Unconstrained**
constant	-10.73425	-10.79950	-10.71180
	0.00	*0.00*	*0.00*
d(gap)		0.07452	0.08855
		0.27	*0.19*
d(ur)		0.00368	0.00379
		0.05	*0.03*
d(pr)		-0.00345	-0.00424
		0.17	*0.09*

The large number is the coefficient estimate, the smaller value underneath is the associated p-value. **ur** refers to the unemployment rate; and **pr** to the participation rate.

Table 4. Gordon Productivity Estimation Results

		HP Filter Models	
Model	**Augmented**	**No pr**	**Unconstrained**
constant	-9.17799	-9.10367	-9.28767
	0.00	*0.00*	*0.00*
gap	0.36983	0.52319	0.36854
	0.01	*0.00*	*0.01*
ur	0.00680	0.01180	0.00812
	0.01	*0.00*	*0.00*
pr	-0.01083		-0.00681
	0.01		*0.09*

The large number is the coefficient estimate, the smaller value underneath is the associated p-value. **gap** refers to the output gap; **ur** to the unemployment rate; and **pr** to the participation rate. All explanatory variables are first differenced.

Table 5. Production Function Estimation Results

Model	Production Function Model
constant	2.92860
	0.00
KL	0.31307
	0.00
TREND	0.00302
	0.00
TREND81	-0.00225
	0.01
TREND90	0.00268
	0.00
TREND00	-0.00163
	0.00

The large number is the coefficient estimate, the smaller value underneath is the associated p-value. **ur** refers to the unemployment rate; **pr** to the participation rate and **kl** to the capital-labour ratio.

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