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THE AUSTRALIAN GROWTH EXPERIENCE
(1960-2000): R&D-BASED, HUMAN
CAPITAL-BASED, OR JUST
STEADY STATE GROWTH?

by

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The Australian Growth Experience (1960-2000): *R&D-Based, Human Capital-Based, or Just Steady State Growth?*

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Abstract

This paper examines the sources of economic growth in Australia from 1960 to 2000 by adapting and modifying a framework developed in Jones (2002), whereby long-run growth is driven by the global discovery of new ideas, which in turn is tied to world population growth. We find that, contrary to the conventional view as suggested by sustained growth rates and a stable capital-output ratio over the last several decades, Australia is clearly not on its steady-state balanced growth path. Australia has benefited from increases in educational attainment and research intensity: 28 percent of Australian growth between 1960 and 2000 is attributable to the rise in educational attainment, about 40 to 60 percent is attributable to increasing research intensity, while only 20 to 30 percent is due to long-run population growth in the idea-producing countries.

KEYWORDS: Economic Growth, Human Capital, Technological Change
JEL CODES: O40, E10

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1 Introduction

Like many industrialised countries, Australia has experienced remarkably sustained growth over the last 100 years. Although her per-capita income rank within the league of advanced economies has fallen several notches over this period, Australia's growth rate has remained fairly stable at an average of 1.7 percent per year. In addition, the capital-output ratio and interest rates have not exhibited any pronounced trends, reinforcing the conventional view that a mature economy like Australia's must be on its long run steady state balanced growth path.

However, at least over the post-World War II period, educational attainment in Australia, as measured by the workforce's average number of years of schooling, has risen. The rapid growth of universities in this period reflects both an expansion of tertiary educational opportunities as well as a rise in Australia's research intensity. The proportion of the workforce engaged in research and development activities has increased significantly, although not as dramatically as in countries such as the US, Japan or Germany.

The stability of Australia's growth rate and the increases in educational attainment and research intensity appear contradictory at first glance. In the neoclassical growth model, such increases lead to transitional dynamics in the form of temporarily higher growth rates followed by a decline in growth and a return to the steady state at a higher level of per-capita income. On the other hand, many endogenous growth models predict that greater educational attainment and research intensity lead to permanently higher growth rates.

In attempting to explain a similar puzzle in US growth data, Jones (2002) proposes the concept of a constant growth path. On such a path, a sequence of transitional dynamics generates growth at a constant average rate above that of the steady-state rate consistent with a true balanced growth path. Jones constructs a theoretical model in which long-run growth is propelled by the global discovery of ideas, which depends on the number of workers involved in research, which itself is a function of the population growth rates of the most technologically advanced countries. We adapt and modify this model, and use the growth accounting exercises that arise naturally from its formulation to study Australian growth between 1960 and 2000. Contrary to the conventional wisdom that the Australian economy is on a balanced growth path, we find that the long-run component of growth probably accounted for no more than a quarter of the total during those years. More than 75 percent of growth was associated with transitional dynamics. Our results indicate that the half-life of the transitional path may be several decades long. We also trace Australia's growth trajectory in the event of a cessation in educational attainment and research intensity increases.

The paper is organised as follows: Section 2 summarizes previous research on Australia's growth experience over the last several decades. Section 3 presents the theoretical model. Section 4 summarises the more interesting aspects of Australian growth data, and discusses the results of growth accounting exercises derived from the theoretical model. Section 5 analyses the transitional dynamics of the model while Section 6 concludes.

2 Background on Australia's Growth Experience

2.1 Historical Australian Total Factor Productivity Levels and Growth Rates

In addition to experiencing sustained growth in income per worker over the last century, Australia has also achieved consistent total factor productivity (TFP) growth during this time. This indicates that Australia's rising per capita income level is not driven solely by factor accumulation, but also through improving efficiency in transforming inputs into output. Figure 1 uses data from Maddison (1995) to illustrate the behaviour of Australian TFP from 1902-96. Although TFP growth rates appear to have fluctuated around a fairly constant mean since WWII, short-run business cycles have naturally caused GDP and TFP growth to vary across decades. Figure 2 shows the level of Australian TFP between 1901 and 1996. Table 1 lists the periods of highest and lowest growth in Australian GDP per capita from 1902 to 1996. With the exception of the 1902-05 sub-period, high TFP growth has generally been associated with GDP growth in Australia.

We now turn to some inter-country comparisons of TFP levels. Figure 3 shows the TFP levels in Australia and the G-5 countries between 1900 and 1995, while Figure 4 illustrates TFP levels in Australia and selected Asian countries between 1960 and 1995. It is obvious that Australia's TFP levels have lagged behind those of the US, Japan, France and Germany since the mid-1950s while only surpassing the UK. Moreover, the impressive performance of the Asian "tigers" since the 1960s means that the positive TFP gap between countries such as Taiwan (or Korea, or Singapore) and Australia has increasingly widened since 1985.

2.2 World Knowledge and the Australian Economy

Because Australia is such a small economy compared to most of its OECD counterparts, Rogers (1997) argues that its internal ability to generate knowl-

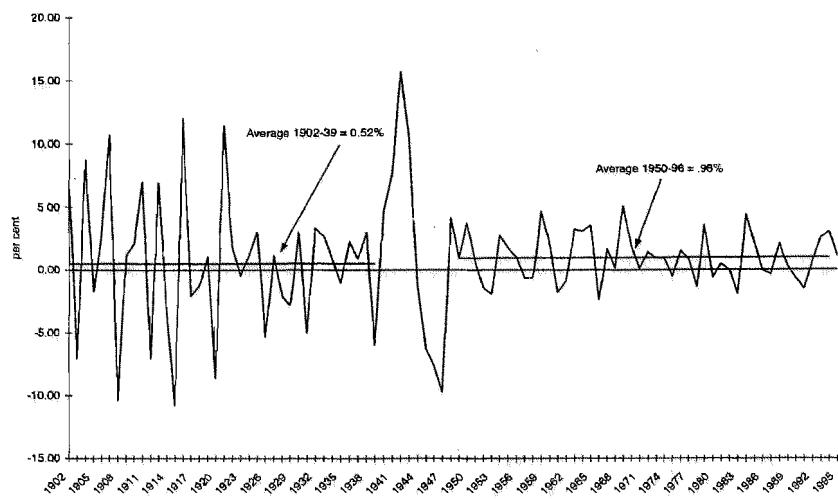


Figure 1: Australian TFP Growth (1902-1996)



Figure 2: Australian TFP (1901-1996)

	Period	GDP growth	TFP growth
Five highest rates of GDP growth	1921-25	4.41	3.39
	1906-10	3.95	1.33
	1941-45	3.75	5.29
	1966-70	3.41	1.26
	1961-65	3.10	1.44
Five lowest rates of GDP growth	1931-35	0.08	0.17
	1902-05	-0.26	1.87
	1911-15	-0.70	-1.48
	1916-20	-1.09	0.23
	1926-30	-1.63	-1.23

Table 1: Periods of highest and lowest growth in Australian GDP per capita

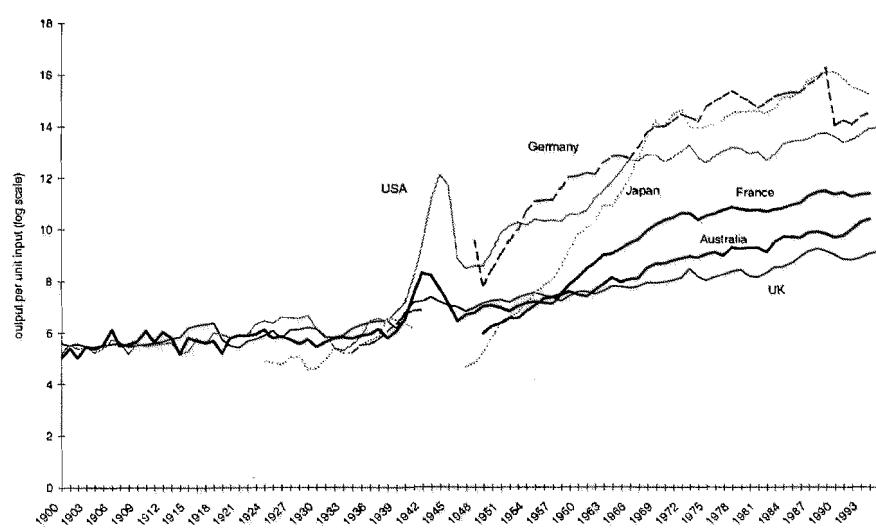


Figure 3: TFP levels, Australia and G-5 Countries

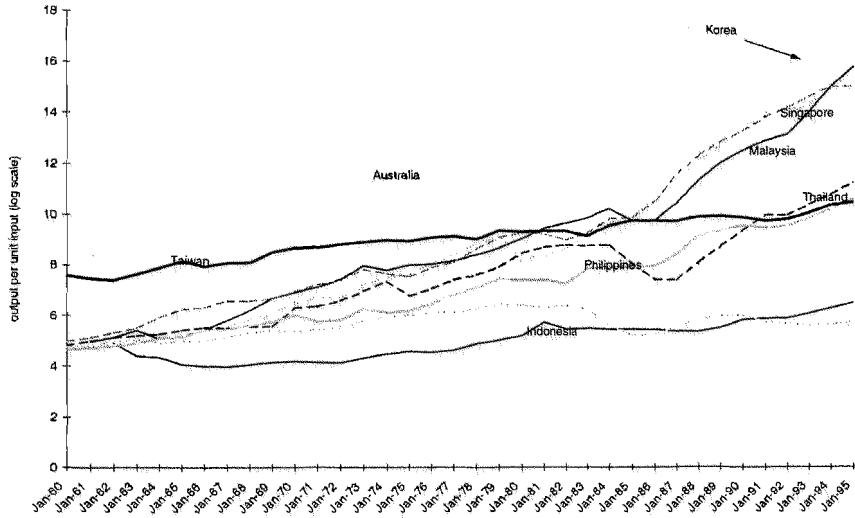


Figure 4: TFP Levels, Australia and Selected Asian Countries

edge from research and development may not be as important as its ability to learn new knowledge from overseas. This involves monitoring, learning and imitating innovations created overseas, and using them as inputs for domestic innovation. Figure 5 shows that Australia's total absolute expenditure on business R&D is dwarfed by the US', Japan's and Germany's. This disparity is also reflected in patent applications: for example, in 1994, US nationals applied for 107,000 patents in the US, while Australian residents applied for 8,000 in Australia. These data suggests that there will always be a vast amount of knowledge generated overseas that Australia cannot hope to invent itself. As Rogers asserts, if Australia is to maintain its international competitiveness, it must be efficient at absorbing overseas knowledge.

To what extent, then, does Australia benefit from innovations created overseas? Coe and Helpman (1995) attempt to assess how much benefit OECD countries obtain from domestic R&D and R&D performed overseas between 1970 and 1990. They find that Australia and Spain (out of the smaller OECD economies) had the smallest gains from overseas R&D, with elasticities of around 0.05, that is, a 1 percent rise in foreign R&D stock increased domestic TFP by only 0.05 percent. Other small developed economies such as Sweden, Canada, Ireland and the Netherlands exhibit elasticities in the 0.08 to 0.18 range (see Figure 6). Rogers (1997) attributes Australia's relative weakness in absorbing new knowledge from overseas to its relatively closed economy, as well

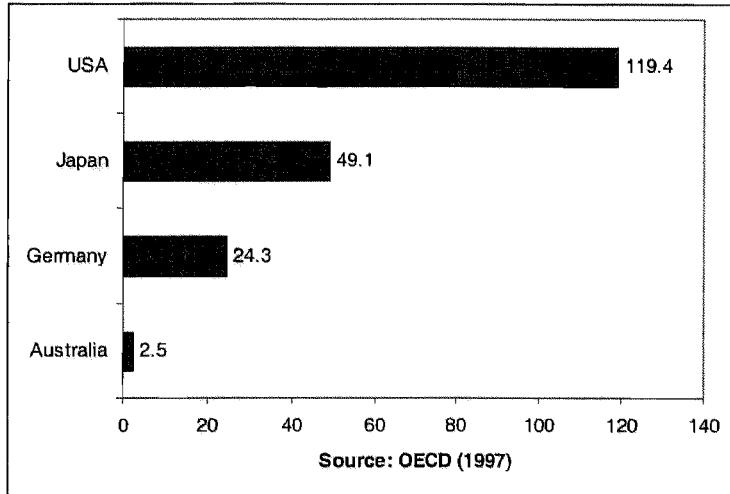


Figure 5: Total Business R&D Expenditures (US\$billion, 1994 Prices)

as the lack of resources and incentives for Australian enterprises to implement new technologies.

On the other hand, Simon and Wardrop (2002) analyses the historical gains from the use of information technology in Australia and finds that Australia has done well out of the ‘new economy’. They conclude that Australia has experienced significant output growth related to computer use and foresees bright prospects for Australia as a user of information technology.

3 The Theoretical Model

In the world constructed in Jones (2002), there exist multiple, disparate countries / economies with different endowments and allocations but similar production possibilities. Ideas that these economies create are the only element in the model that links them to one another, since there is no trade in goods, while capital and labour are assumed to be immobile. In Jones’ paper, new ideas are only created in the G-5 countries (namely, the US, UK, Japan, France and Germany), and these ideas are instantly diffused from one country to the next. Here, we assume that research on new ideas is carried out in Australia as well as in the G-5 nations. However, only some of the efforts devoted to idea or knowledge creation abroad are useful in improving Australia’s production technology. This proportion depends on how much resources Australia channels into domestic research.

In Australia, the production of the final consumption good, Y_t , is given by

$$Y_t = K_t^\alpha (A_t H_{Yt})^{1-\alpha}, \quad (1)$$

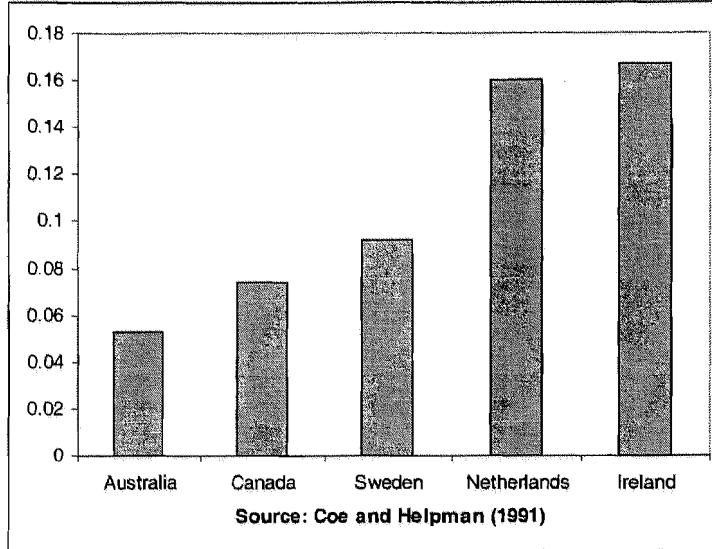


Figure 6: Effect of Domestic TFP of a 1 Percent Increase in Foreign R&D Knowledge Stock (1990, Percent)

where K_t is physical capital, H_{Yt} is the total amount of human capital employed in producing output, and A_t is the total stock of useful ideas in Australia. We assume that $0 < \alpha < 1$. The production function exhibits constant returns to scale with respect to physical and human capital, and increasing returns with respect to these plus ideas, reflecting the non-rival nature of ideas.

Physical capital accumulates according to

$$\dot{K}_t = s_{Kt}Y_t - dK_t, \quad (2)$$

where s_{Kt} denotes the saving or investment rate, and $d > 0$ is the constant rate of depreciation.

Aggregate human capital that is employed in producing output is given by

$$H_{Yt} = h_t L_{Yt}, \quad (3)$$

where h_t is human capital per person and L_{Yt} is the total amount of raw labor employed in the production of the final good. Following Mincer (1974) and the subsequent body of literature on schooling and wages (including Bils and Klenow (2000)), at the individual level human capital is produced by spending time away from the labor force according to:

$$h_t = e^{\psi l_{ht}}, \quad \psi > 0, \quad (4)$$

where l_{ht} is fraction of the population that is schooling and therefore not working, or the fraction of an individual's total time endowment that is spent accumulating human capital.

New ideas are created by researchers in Australia and the G-5 countries according to the production function discussed in Jones (1995):

$$\dot{A}_t = \delta H_{At}^\lambda A_t^\phi, \quad (5)$$

where H_A is, in this case, effective research effort, governed by

$$H_{At} = H_{At, Aus}^\omega \cdot H_{At, G-5}^{1-\omega}.$$

$H_{At, Aus}$ denotes human resources devoted to research in Australia at time t while $H_{At, G-5}$ denotes its G-5 counterpart. The parameter ω is constrained to lie in the $[0,1]$ interval. If ω is large, then Australia is relatively dependent on its own researchers and relatively poor in learning from the efforts of G-5 researchers, insofar as technological improvements are concerned. Notice that if Australia devotes no resources to research, no new ideas concerning production technologies are created. This captures the idea that absorbing knowledge from abroad requires domestic human capital to assimilate this knowledge. In addition,

$$\begin{aligned} H_{At, Aus} &= h_t^\theta L_{At, Aus}, \\ H_{At, G-5} &= \sum_i h_{it}^\theta L_{Ait}, \end{aligned} \quad (6)$$

where the summation in the second equation is across the G-5 countries, i indexes countries, L_{Ai} is the number of researchers in country i , and $\theta \geq 0$. G-5 research effort is therefore the weighted sum of the number of researchers in each economy, with the “quality” weights adjusting for human capital. The model clearly shows the level at which the scale effect associated with the non-rivalry of knowledge operates: in the real world, the relevant scale is the population in the group of countries that are sufficiently close to the world technological frontier that they can meaningfully contribute to the global discovery of new ideas. As specified, the model predicts that an increase in the aggregate population of this group of countries raises long-run per capita growth by increasing the number of workers engaged in research.

We assume that there are N_t individuals in Australia, which grows at the exogenous rate $n > 0$. Every individual is endowed with a single unit of time, divided between producing final goods, creating ideas and accumulating human capital. As time spent in school is excluded from labour force data, the resource constraint may be written as

$$L_{At} + L_{Yt} = L_t = (1 - l_{ht})N_t, \quad (7)$$

where L_t is employment. We define $l_A \equiv L_A/L$ as the fraction of the labour force that is devoted to creating ideas and term it “research intensity”, while $l_Y \equiv L_Y/L$.

The economy exhibits a stable, balanced growth path (BGP) where all variables grow at constant, exponential rates forever and along which labor allocations must be constant. On this path, the growth rate of output per worker is proportional to the growth rate of effective world research H_A . Moreover, since h is constant along the BGP, growth in effective world research is driven by population growth.

3.0.1 Deriving the Growth Decomposition Equations

First we rewrite the production function in equation (1) in per capita terms:

$$y_t \equiv Y_t/L_t = \left(\frac{K_t}{Y_t} \right)^{\frac{\alpha}{1-\alpha}} l_{Yt} h_t A_t. \quad (8)$$

Along a balanced growth path, all terms on the right-hand side except for the last are constant. Therefore, the growth rates of y and A (denoted by g_Y and g_A) are equal. From equation (5), we can solve for g_A to obtain $g_A = \gamma n$ where $\gamma \equiv \lambda/(1 - \phi)$.

We then take logs on both sides on the equation to decompose the growth rate of output per worker between any two points in time into its constituent components, thereby obtaining our first decomposition equation:

$$\hat{y}_t = \frac{\alpha}{1-\alpha} (\hat{K}_t - \hat{Y}_t) + \hat{h}_t + \hat{l}_{Yt} + (\hat{A}_t - \gamma n) + \gamma n, \quad (9)$$

where a hat ($\hat{\cdot}$) is used to denote the average change in the log of a variable between two points in time. For example, $\hat{y}_t = 1/t * (\log y_t - \log y_0)$. We add and subtract the steady-state growth rate γn so that the equation has the following convenient interpretation: all terms except the last are zero in the steady-state. If the conventional view that the Australian economy is close to its balanced growth path is correct, this last term should account for a large proportion of observed growth.

As Jones (2002) points out, the decomposition in equation (9) is valid across any points in time under very weak assumptions and is not merely a steady-state relationship. In addition, this accounting exercise is similar in spirit to Solow (1957), Denilson (1962) and others, but total factor productivity growth is endogenised in this framework through the specification of a complete growth model.

We now proceed to derive our second decomposition equation. Suppose the stocks K and A grow at constant rates (which in turn requires H_A to grow at a constant rate), keeping in mind that stocks may be inferred from flows when growth rates are constant. Then output per worker in equation (8) may

be decomposed as

$$y_t = \left(\frac{s_{Kt}^*}{n + g_k + d} \right)^{\frac{\alpha}{1-\alpha}} l_{Yt} h_t \left(\frac{\delta}{g_A} \right)^{\frac{\gamma}{\lambda}} H_{At}^{*\gamma}, \quad (10)$$

where $k \equiv K/L$. An asterisk above a variable denotes a quantity that is growing at a constant rate. The first term in parenthesis is simply the capital-output ratio, which is proportional to the investment rate when the capital stock grows at a constant rate, as in the standard Solow model. The last term in the equation derives from the fact that as the stock of ideas A grows at a constant rate, this stock may be inferred from the flow of research effort H_A .

We now impose our assumption that researchers have the same, unchanging skill level, which is normalized to one.¹ Therefore, $H_A = (l_A L)^\omega \cdot (\tilde{l}_A \tilde{L})^{1-\omega}$, where L denotes Australian employment, l_A is Australian research intensity, \tilde{L} denotes G-5 employment and \tilde{l}_A is G-5 research intensity. In addition, for elegance's sake, we define $\xi_K \equiv \frac{s_{Kt}^*}{n + g_k + d}$ and $v \equiv (\delta/g_A)^{\gamma/\lambda}$. Equation (10) may therefore be re-written as:

$$y_t = \xi_{Kt}^{\frac{\alpha}{1-\alpha}} l_{Yt} e^{\psi l_h t} v l_{At}^{\gamma \omega} \tilde{l}_A^{\gamma(1-\omega)} \tilde{L}_t^{\gamma(1-\omega)}. \quad (11)$$

Now assuming that each of the terms on the right-hand side is growing at a constant rate, taking logs and differencing equation (11) to approximate the growth rate yields

$$g_y = \frac{\alpha}{1-\alpha} g_{\varepsilon_K} + g_{l_Y} + \psi \Delta l_h + \gamma \omega g_{l_A} + \gamma (1-\omega) g_{\tilde{l}_A} + [\gamma \omega n + (1-\omega) \gamma \tilde{n}], \quad (12)$$

where n is the growth rate of Australian employment, and \tilde{n} is the growth rate of G-5 employment.

In the steady state, every term in equation (12) is zero except the last in square brackets, so this equation reduces back to the condition $g_y = \gamma \omega n + \gamma (1-\omega) \tilde{n}$. Away from the steady-state, the growth rate of output per worker may be constant and above its long-run growth rate because of growth in the human capital investment rate l_h and in research intensities l_A and \tilde{l}_A . Obviously this situation cannot last forever, since these shares are bounded from above at one.

Note that if there is zero diffusion of knowledge from G-5 countries to Australia (that is, $\omega = 1$), then two of the terms on the right hand side of equation (12), $\gamma (1-\omega) g_{\tilde{l}_A}$ and $(1-\omega) \gamma \tilde{n}$, would be equal to zero.

¹That is, we set $\theta = 0$.

4 Empirical Analysis

The preceding theoretical model provides a framework for analyzing growth in a particular country, whereby the engine of long-run growth is the *global* creation of ideas. We now apply it to analyze Australia's growth experience between 1960 and 2000.

4.1 Data Summary

A detailed description of the data is given in Appendix B. The data on GDP per hour worked and on the factors of production corresponding to the quantities in equation (8) are shown in Figure 7. Overall they appear to grow at roughly constant rates, although GDP per hour worked appears to have been relatively stagnant in the 1980s. The capital-output ratio is fairly stable while human capital per worker is rising due to increasing educational attainment, as shown in Figure 8. The increase in educational attainment is similar to that seen in the US. While US educational attainment rose from approximately 8.5 years to 12.5 years by 1993, its Australian counterpart increased from about 9 years in 1960 to 13 years in 2000.² In principle, we would like to measure skills obtained outside the formal education process when computing human capital per worker, but such data is difficult to obtain.³ It will also be tricky to merge this data, even if available, with the data on years of schooling. For example, we may need to work out the equivalence scale between one year of formal schooling and three months' enrolment in a worker re-training or skill-upgrading programme.

With Australia being a relatively small economy, improvements in Australia's production technology must come at least partly from research con-

²In mapping the educational attainment data into l_h , we assume that an individual's labour endowment has remained constant. As in the US, rising life expectancy has been offset by a decline in the retirement age, as the following quote from a document prepared by the Department of Social Security on the Australian Institute of Health and Welfare web site suggests: "There is an increasing trend towards earlier retirement, that is, withdrawal from the labour force before pension age (65 years for men and 61 years for women). According to data from the Australian Bureau of Statistics, in 1994, 74% of men and 87% of women had already retired from full-time work during the five-year period preceding their eligibility for age pension. This may be voluntary or, alternatively, given the major restructuring of the economy over recent years, many older workers may have been retrenched, with little possibility of re-entering the labour force."

³The Australian Bureau of Statistics collects data on the training experiences of workers (including participation in training courses and on-the-job training), but only from 1989 onwards. The relevant publication is ABS 6278.0.

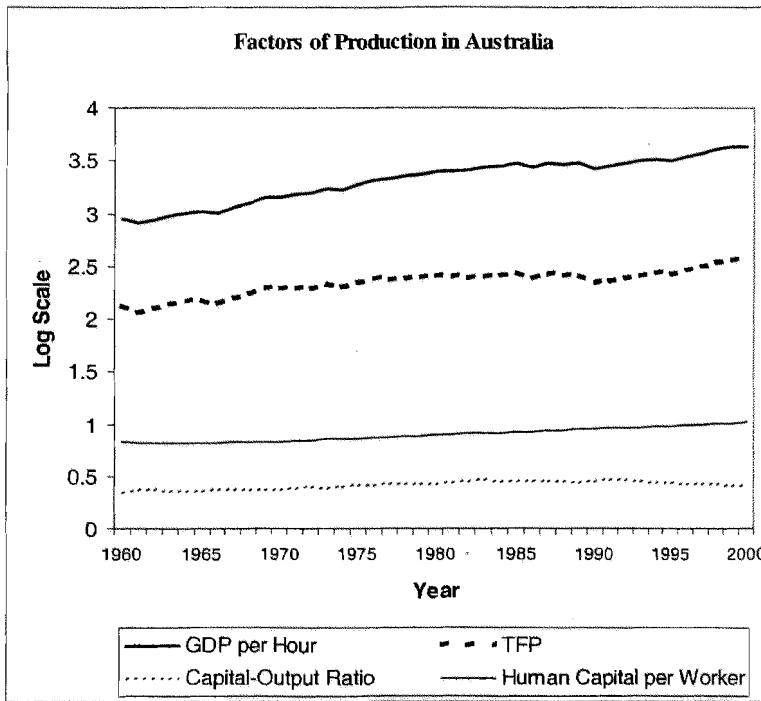


Figure 7: Factors of Production in Australia

ducted abroad. We preserve the assumption in Jones (2002) that only researchers in the G-5 countries (France, West Germany, Japan, UK, and US) are capable of extending the global frontier of knowledge. We exclude medium-sized developed countries such as Italy partly because of their lack of data before the 1980s, but also because the majority of world research effort is undertaken in the G-5 countries. In addition, we assume that the “quality” of these researchers is identical across these countries and has remained constant over time. The justification is that in order to be hired as a researcher, one has to have attained a certain level of education, so that the rise in average educational attainment has little bearing on the quality of researchers. Figure 9 shows research intensity (the number of employed R&D workers as a ratio of total employment) in Australia from 1976 to 2000, while Figure 10 reproduces the corresponding figure for the G-5 countries shown in Jones (2002). Between 1950 and 1993, research intensity in the G-5 countries rose by an average of 3.6 percent per year. In Australia, research intensity only increased by an annual average of 2 percent between 1976 and 2000. (Note, however, that the definition of an R&D worker differs between the Australian case and the case of the G-5 countries. See the Appendix on how the data for the two cases are obtained). A similar picture is also painted in Figure 11, which plots the percentages of total R&D expenditures and business R&D to GDP (labelled

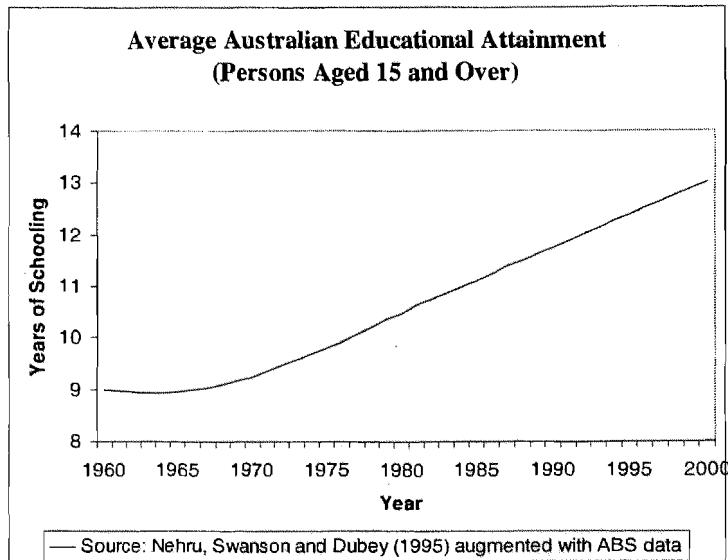


Figure 8: Average Educational Attainment of the Australian Labour Force (1960-2000)

GERD and BERD respectively) for various OECD countries in the 1990s.

4.2 The Growth Accounting Exercises

We now report the results from the growth accounting exercises derived from the theoretical model presented in Section 2. Many of the empirical counterparts of the variables in equation (9) are readily observed. The key growth rates needed for the accounting decomposition are reported in Table 2. What is required, then, are suitable values for the parameters in that equation. We assume a value of 1/3 for the capital coefficient, α , based upon data on capital's share of income.

The parameter ψ is inferred from microeconomic evidence. If we interpret l_h as years of schooling, then ψ corresponds to the return to schooling estimated by Mincer (1974) and others using log-wage regressions. Output per worker, and thus the wage, differs across workers in the same economy with different amounts of schooling with a semi-elasticity of ψ . The labour market literature suggests a reasonable value of .07 for ψ . This means that an extra year of schooling has a direct effect of raising labour productivity by 7 percent.

The parameter γ is a combination of parameters from the idea production function (specifically, $\gamma = \frac{\lambda}{1-\phi}$) and is therefore more tricky to obtain. We first divide both sides of the production function for ideas in equation (5) by A_t

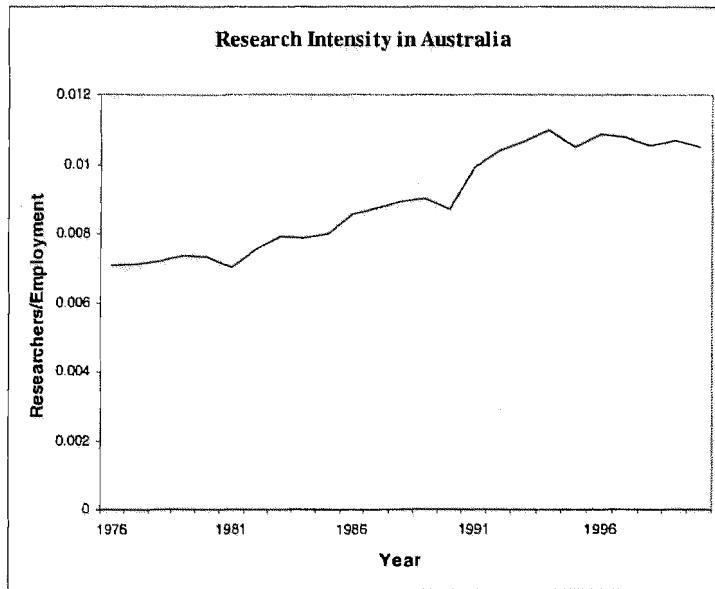


Figure 9: Research Intensity in Australia (1976-2000)

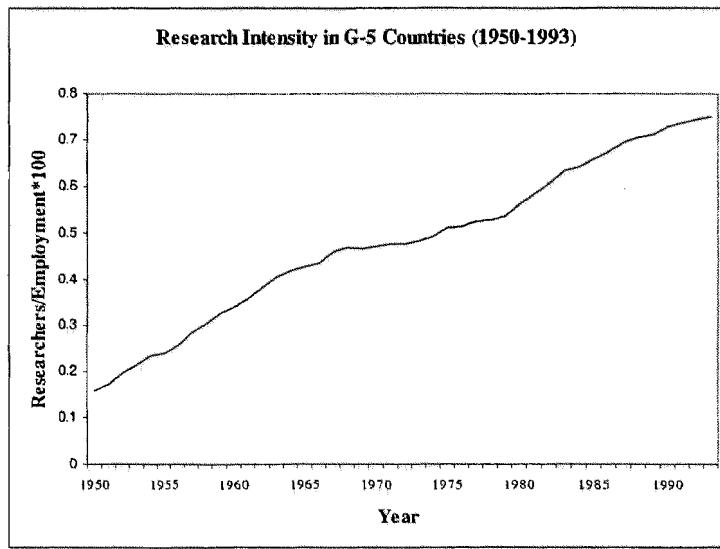


Figure 10: Research Intensity in G-5 Countries (1953-1990)

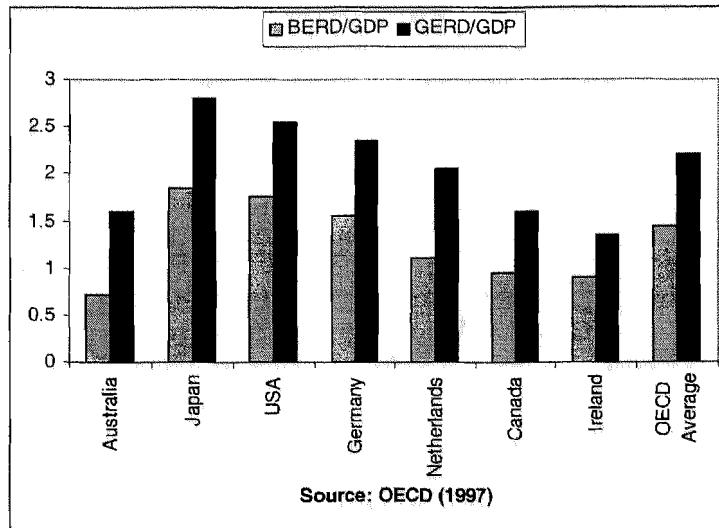


Figure 11: Australia and OECD R&D Intensity

and rewrite the coefficients in terms of γ :

$$\frac{\dot{A}_t}{A_t} = \delta \left(\frac{H_{At}^\gamma}{A_t} \right)^{1-\phi}. \quad (13)$$

The numerator in the brackets is the quantity of “global” human capital used in producing ideas, while the denominator is the level of productivity. If total factor productivity truly exhibited no trend between 1960 and 2000, the parameter γ would be equal to the ratio of the growth rates of total factor productivity and H_A . This rough, back-of-envelope calculation using the values given in Table 2 yields a value of $.0106/.0483 = 0.219$ if G-5 innovations diffuse freely into Australia (that is, $\omega = 0$) and a value of $.0106/.0311 = 0.341$ if Australia relies entirely on domestic R&D ($\omega = 1$). In his analysis of US growth data, Jones (2002) performs econometric analysis of the estimation of γ which yields a high value of about $1/3$ to a low value of about $.05$.⁴ Taking all these into consideration, we choose the following three values for γ : $.050$, $.200$, $.333$, and $.500$.⁵

With these choices for the parameter values and the data from Table 2 in place, we are ready to perform the growth decomposition implied by equation (9). The results are reported in Table 3. Real output per hour grew at

⁴One of the econometric exercises involves regressing $\log H_{At}$ on $\log B_t$ using OLS. In our case, this produces an estimate of γ of 0.332. The adjusted R -square is this regression is 0.739.

⁵Note that, empirically, A itself is recovered from the data in the traditional manner, that is, being directly calculated from equation (8).

an average annual rate of 1.71 percent between 1960 and 2000 in Australia. The stability of the investment rate translated into a relatively stable capital-output ratio, giving rise to a very modest 0.19 percentage point contribution to growth. In addition, there was a minute reallocation of labour from final goods production to the production of ideas, so that the composition effect associated with this change has virtually no impact on output per hour.

The rise in educational attainment contributed .47 percentage points to growth in output per hour, thereby accounting for 27.5 percent of growth between 1960 and 2000. This figure is slightly lower than the figure of 31.5 percent for the US reported in Jones (2002). This reflects the fact that mean educational attainment rose comparably in Australia and the US.

What, then, accounts for the rest of Australian growth? The remaining 62 percent of growth must be attributed to the rise in the stock of ideas produced by researchers in Australia as well as the G-5 countries. This effect has two components: firstly, the growth in the stock of ideas in excess of the steady-state rate is the largest contributor to growth in this decomposition exercise, accounting for between 0.46 to 1 percentage point or 27 to 59 percent of growth, depending on the chosen value for γ . Secondly, the steady-state component, associated with the general rise in Australian and G-5 employment, contributed between .06 to .60 percentage points (or 4 to 35 percent) to growth in Australian output per hour between 1960 and 2000.

In this model, steady-state growth is generated entirely by population growth in Australia and the G-5 countries, as per capita growth requires growth in the stock of ideas which in turn requires growth in the number of researchers. The decomposition shown in Table 3 shows that less than 40 percent of Australian growth between 1960 and 2000 is due to this scale effect. Conversely, more than half of Australian growth in this period is due to the transitional dynamics associated with educational attainment and the stock of ideas. By way of comparison, steady-state growth accounted for 3 to 20 percent of US growth between 1950 and 1993, while growth in the stock of ideas in excess of the steady-state rate contributed between 53 to 70 percent of total US growth.⁶

In short, between 1960 and 2000, Australia's total factor productivity (recovered from the production function for final goods, as discussed earlier) grew at a rate, 1.71 percent per annum, in considerable excess of its steady-state long-run rate, which is determined by a weighted average of the population growth rates of all countries advanced enough to contribute to the global pool of ideas.

⁶Figures from Jones (2002). The ranges given are smaller because γ only takes on the alternative values of .05, .20 and .333, omitting .50.

Growth Rate of	Variable	Sample Value
Output per hour	\hat{y}	.0171
Capital-output ratio	$\hat{K} - \hat{Y}$	.0039
Share of labour in goods	\hat{l}_Y	-.0001
Human capital	\hat{h}	.0047
Total factor productivity	\hat{A}	.0106
Annual change in l_h	Δl_h	.1009
R&D labour, Australia	\hat{H}_A	.0311
R&D labour, G-5	$\tilde{\hat{H}}_A$	.0483
G-5 labour force	\tilde{n}	.0120
Share of labour in R&D	$\tilde{\hat{l}}_A$	.0363

Note: See the appendix for data sources. A tilde \sim is used to distinguish a “global” aggregate (a G-5 total) from an Australian value.

Table 2: Average Annual Growth Rates (1960-2000)

4.2.1 The Constant Growth Path Hypothesis

If more than half of Australia’s recent growth is due to transitional dynamics, then why does one not observe the traditional signature of a transition path, such as a gradual decline in growth rates to their steady-state level? Pondering the similar conundrum observed in US data, Jones (2002) argues that at some level, it must be because the transitional dynamics associated with the various factors of production so happen to offset in such a manner so that the growth rate of output per worker remains fairly constant. He then hypothesizes that there exists a constant growth path (or CGP) where all growth rates are constant, but is distinguished from a balanced growth path in that it is not a situation that can persist forever. This, then, is the justification for the derivation of equation (12).

Table 4 shows the results from the growth decomposition exercise which assumes a constant growth path. We first adopt the assumption used in the theoretical model that there is full diffusion of knowledge and ideas from G-5 countries into Australia. Note that all the terms in equation (12) are observed, so we use the equation to deduce the value of γ . We find this to be 0.298, which is near the middle of the range of values for γ used earlier.

The results from the CGP decomposition are fairly consistent with the results obtained from the first growth accounting exercise. Transitional dynamics associated with rising educational attainment and research intensity account for 90 percent of growth in output per hour. With negative contributions

— Transitional Dynamics —						
	Output per Hour	Capital Intensity	Labour Reallocation	Educational Attainment	Excess Idea Growth	Steady State Growth
γ	\hat{y}	$\frac{\alpha}{1-\alpha} (\hat{K} - \hat{Y})$	\hat{l}_Y	\hat{h}	$\hat{A} - \gamma\tilde{n}$	$\gamma\tilde{n}$
0.050	0.0171 (100.0)	0.0019 (11.1)	-0.0001 (0.6)	0.0047 (27.5)	0.0100 (58.5)	0.0006 (3.5)
0.200	0.0171 (100.0)	0.0019 (11.1)	-0.0001 (0.6)	0.0047 (27.5)	0.0082 (48.0)	0.0024 (14.0)
0.333	0.0171 (100.0)	0.0019 (11.1)	-0.0001 (0.6)	0.0047 (27.5)	0.0066 (38.6)	0.0040 (23.4)
0.500	0.0171 (100.0)	0.0019 (11.1)	-0.0001 (0.6)	0.0047 (27.5)	0.0046 (26.9)	0.0060 (35.1)

Note: This table reports the growth accounting decomposition corresponding to equation (9). Numbers in parentheses are percentages of the growth rate of output per hour.

Table 3: Accounting for Australian Growth (1960-2000)

to growth from labour reallocation and changes in capital intensity, the scale effect of G-5 labour force growth accounts for 0.36 percentage points or 21 percent of growth in Australian output per hour. This compares with the high of 35 percent in the previous growth accounting exercise.

If we then assume that there is zero diffusion of ideas from G-5 countries so that Australia's growth (even in the long run) is solely driven by Australian R&D, the contribution of R&D intensity decreases significantly to 40 percent.⁷ The long-run component of growth rises to 44 percent. Results for the intermediate case (corresponding to setting $\omega = 1/2$), where there is partial diffusion of knowledge from overseas, are shown in the middle column of the table. Clearly, prospects for future growth in Australia hinge on faster increases in its R&D intensity, as well as improvement in its absorption of new knowledge from overseas.

In summary, the results from the two growth accounting exercises indicate that the growth rates experienced in the Australian economy over the last 40 years are not consistent with those of an economy in its steady state. The rise in educational attainment and research intensity, however, cannot continue indefinitely. At the very most, the entire labour force can be devoted to the production of ideas, while individuals can spend no more than their entire lives acquiring human capital. The conventional pattern of transitional dynamics will eventually set in when increases in these variables taper off; the economy will then settle slowly into its long-run growth rate, given by $g_y = \gamma\tilde{n}$ in the model.

5 Transitional Dynamics

Like Jones (2002), we are interested in analyzing the model's transitional dynamics away from the constant growth path. The experiment is as follows: suppose the economy is growing at 2 percent annually because of rising educational attainment and research intensity. Then, at some point in time, these plateau (that is, l_h and l_A stabilise). Can we say something about the transitional dynamics as the economy approaches its steady state? More specifically, how long does it take before the growth rate of total factor productivity is halved?

It turns out that when research intensity becomes constant, the differential equations governing the growth rate of A and the stock of A can be solved

⁷Here, we assume a long-run population growth rate of 1.2 percent for Australia and the G-5 countries.

Description	Variable	Sample Value (Percent of g_y)		
		$\omega = 0$	$\omega = 1/2$	$\omega = 1$
	<i>Full Diffusion of G-5</i>			
	<i>Partial Diffusion</i>			
	<i>No Diffusion</i>			
	<i>R&D</i>			
Growth Rate of Y/L	g_y	.0171 (100)	.0171 (100)	.0171 (100)
<i>Equals</i>				
Capital Intensity Effect	$\frac{\alpha}{1-\alpha} g_{\xi_K}$	-.0019 (-11.1)	-.0019 (-11.1)	-.0019 (-11.1)
+ Effect of Labour	g_{l_Y}	-.0001 (-0.6)	-.0001 (-0.6)	-.0001 (-0.6)
Reallocation				
+ Educational Attainment Effect	$\psi \Delta l_h$	.0047 (27.5)	.0047 (27.5)	.0047 (27.5)
+ R&D Intensity Effect	$\gamma g_{l_A}, \gamma g_{l_A}$	.0108 (63.2)	.0096 (56.1)	.0069 (40.4)
+ Scale Effect of Labour Force	$\gamma \tilde{n}, \gamma n$	.0036 (21.1)	.0048 (28.1)	.0075 (43.9)

Numbers in parenthesis are percentages of the growth rate of output per hour.

Table 4: Constant Growth Path Decomposition (1960-2000)

analytically. Let $x_t \equiv \dot{A}_t/A$ denote the growth rate of the stock of ideas. With constant research intensity, it is easy to show that this growth rate satisfies the following differential equation:

$$\frac{\dot{x}_t}{x_t} = \lambda n - \frac{\lambda}{\gamma} x_t. \quad (14)$$

The differential equation can then be solved to obtain

$$\frac{x_t - x^*}{x_t} = \frac{x_0 - x^*}{x_0} e^{-\lambda nt}, \quad (15)$$

where x^* denotes the steady-state growth rate of A .

The above equation allows us to solve for the half-life of the transition to the steady state. The equation tells us that the speed of convergence using a long-linear approximation is simply λn . The half life is then given by $\sqrt{2}/\gamma n$. Column 3 in Table 5 shows that the half-lives from the log-linear approximation are relatively large, ranging from 69 to 278 years, depending on the value of γ . Using equation (15) directly enables us to derive the half-life exactly. Suppose the population growth rate (n) is one percent while the initial TFP growth rate (x_0) is 1.06 percent, the Australian historical average between 1960 and 2000. The steady-state growth rate, x^* , equals γn . Columns 4-6 in Table 5 show the computed half-lives for different combinations of values for λ and γ . They are extremely sensitive to the choice of γ and range from 5 to 240 years. In general, they are considerably smaller than the figures obtained from the log-linear approximation.

The differential equation in (15) may itself be solved. The level of total factor productivity at time t is given by

$$A_t = A_0 \left(\frac{x_0}{x^*} e^{\lambda nt} + 1 - \frac{x_0}{x^*} \right)^{\gamma/\lambda}. \quad (16)$$

We use this equation to plot the time path of A_t under the counterfactual that research intensity had levelled off in 1960 instead of growing as steadily as it did. Using a intermediate value of $\gamma = .20$, Figure 12 shows that the level of productivity is 20.5 percent below trend after 50 years for $\lambda = 1$, and 9.5 percent for $\lambda = 1/4$.

6 Conclusion

In this paper, we used a framework adapted from Jones (2002) to analyse Australia's growth experience in the four decades from 1960 to 2000. The

λ	λn	Log-Linear Approx.	— Exact Half-Life for —		
			$\gamma = .33$	$\gamma = .20$	$\gamma = .05$
1	0.010	69.3	60.2	26.5	5.1
1/2	0.005	138.6	120.3	52.9	10.2
1/4	0.003	277.3	240.6	105.9	20.3

Note: Half-Lives Calculated from equation (15) assuming $x_0 = .0126$ and $n = .01$.

Table 5: Half-Life of Total Factor Productivity Growth

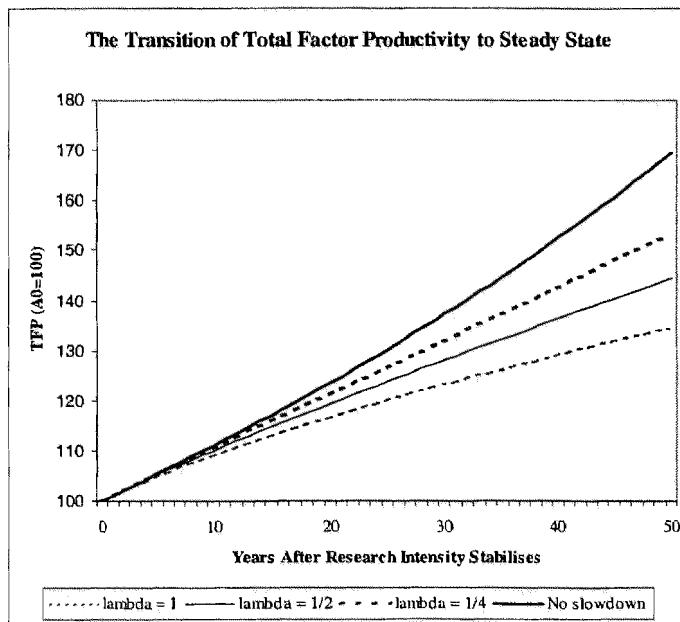


Figure 12: The Transition of Total Factor Productivity to Steady State

framework consists of a theoretical endogenous growth model which is calibrated using country-level data. In this model, long-run steady-state growth arises from local as well as global research and development of new ideas, which depends on the number of workers engaged in such efforts locally and abroad, and is ultimately linked to the population growth rates of countries on the technological frontier.

We then used the theoretical model to derive two growth accounting exercises to explain the observation that Australia has experienced sustained growth over a long period of time while its educational attainment, research intensity and adoption of foreign innovations have also been rising. This apparent contradiction is plausibly explained, if not conclusively resolved, using the idea of a constant growth path. On the constant growth path, a sequence of transitional dynamics generates growth at a constant average rate above that of the steady-state rate consistent with a true balanced growth path.

The accounting exercises show that Australian growth between 1960 and 2000 can be attributed to three sources. The first two are associated with transitional dynamics, and account for more than half of the growth in output per worker. Increases in educational attainment account for 28 percent of growth, while rising research intensity in Australia as well as G-5 countries (and Australia's absorption of these innovations) account for 27 to 59 percent of growth. Between 4 to 35 percent of growth is associated with its long-run component that, in the theoretical model, is driven by rising Australian and G-5 employment.

The prospects for Australian growth continues to look bright for the near future as there still exists ample room for research intensity to grow. This is due to an expanding global market for ideas as well as the inevitable increase in the share of the world's population that possesses the necessary skills to propel the technological frontier forward. Ultimately, however, these increases must cease in the very long run and Australian growth rates (as well as those of other countries) will then decline significantly.

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A Data Sources

The data used in this paper are taken primarily from Australian Bureau of Statistics (ABS) publications.

GDP per Hour. Data on real GDP in constant 1999/2000 Australian dollars are taken from Table G09 on the Reserve Bank of Australia website (<http://www.rba.gov.au>) and are averaged over quarters. Employment is converted into total hours using data on average hours worked by full-time and part-time employed workers in all industries (aged 15 and above) from the ABS 6203.0 Labour Force Survey (May 1966-May 2000, annual), and assuming a constant work year. The data for 1960-1965 are extrapolated using information from the ABS Survey of Wage Rates, Earnings and Hours (1962, 1963, 1966-1970)..

Educational Attainment. 1960 to 1987 data from the database on human capital stock by Nehru, Swanson and Dubey (1995) are combined with 1981-1993 data from ABS 6235.0 (Labour Force Status and Educational Attainment, Australia) to compute the average years of schooling of employed workers. Nehru et al.'s series is built from enrolment data using the perpetual inventory method, adjusted for mortality. Estimates are corrected for grade repetition among school-goers and for country-specific drop-out rates for primary and secondary students. Details on how the final figures are derived may be obtained from the author via e-mail. Initially, updated 1960-1995 data from the Barro and Lee dataset (available on the Harvard CID web site) was used, but this approach was discarded when the implied growth rates of educational attainment were implausibly low and at odds with the presumably more reliable ABS survey data. For example, according to the Barro and Lee dataset, average educational attainment in Australia only increased from 9.43 years in 1960 to 10.57 years in 2000.

Employment. Seasonally-adjusted data on Australian employment from 1966 to 2000 are from ABS 6204.0. (The figures from 1982 onwards, catalogued as ABS 6291.0.40.001 Table 9i, may be found at <http://www.abs.gov.au/ausstats/abs%40.nsf/lookupresponses/6090456db654781bca25688d001eba74?open-document>.) The figures chosen are for the month of May (1967-77), June

(1978-2000), and August (1966), while the figures for 1960-1965 are interpolated.

Physical Capital. Data on the physical capital stock (dwellings plus other buildings and structures plus machinery and equipment plus ownership transfer costs plus software plus mineral exploration plus livestock plus artistic originals) for the month of June each year are taken from ABS 5204.066.

Investment. Data on the investment rate is taken to be the saving rate given in the ABS report on the national capital account.

Population growth rate. Data on the annual population growth rate is drawn from ABS 3101 and averaged over quarterly year-on-year growth rates.

Scientists and Engineers Engaged in R&D. The Australian data (available for the years 1976, 1978, 1981, 1984-88, 1990, 1992, 1994, 1996 and 1998) are from ABS 8112.0. The figure illustrating research intensity in Australia (Figuree 9) is obtained by a combination of quadratic and exponential interpolation. The data for the G-5 countries are drawn from Jones (2002), who obtained 1965-1993 data from National Science Board (1993) and National Science Board (1998). For years prior to 1965 for France, Germany, Japan and the UK, Jones assumes that the ratio of research intensity between these countries and the US in 1950 is the same as in 1965. In addition, research intensity for intervening years is linearly interpolated for each country and then multiplied by employment to obtain an estimate for scientists and engineers engaged in R&D. This data is only used to construct the aggregate G-5 researchers series and research intensity, and not used on a country-by-country basis.

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