GDP Growth, Terms-of-Trade Effects, and Total Factor Productivity

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2 authors:

Kevin J Fox
UNSW Sydney

Ulrich Kohli
University of Geneva

GDP Growth, Terms-of-Trade Effects, and Total Factor Productivity

Kevin J. Fox and Ulrich Kohli *

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Abstract

The purpose of this paper is to assess the contribution of each one of the major factors explaining Australian nominal GDP growth: technological change, movements in the terms of trade, increases in the endowments of labour and capital, and changes in domestic output prices. We use an index number technique as well as an econometric approach. Moreover, we look at several methods to decompose total factor productivity growth into secular and unexpected components. All our empirical results have a tight theoretical foundation, being based on the GDP function approach to modeling the production sector of an open economy.

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1 Introduction

From 1960 to 1992, Australian nominal GDP growth has averaged almost 11% annually. Of course, much of this advance is due to price increases, but real growth has nevertheless been substantial. It is generally admitted that Australia's economic performance is very dependent on the movements of her terms of trade. Because a very large share of Australian exports consists of farm products and raw materials, Australia is thought to be quite vulnerable to a fall in the relative price of commodities. Over the years, Australia's terms of trade have been rather volatile. More seriously, they have tended to worsen on average: from 1960 to 1992, the terms of trade have fallen by approximately 16%. This raises the question of the size of the welfare loss that is involved. More precisely, how, and by how much, has Australia's GDP growth been affected by the movements in the relative price of traded goods?

Recently, there has been a regain of interest in the search for the causes of economic growth.[1] Previous work has generally neglected the impact of terms-of-trade changes. This is all the more surprising that many of the countries being scrutinized are very open economies. As noted by Diewert and Morrison (1986), an improvement in the terms of trade is similar to a technological advance since it makes it possible for a country to increase its net output for any given amount of domestic inputs. A deterioration, on the other hand, is equivalent to technological regress, and it reduces the net amount of goods that a country obtains for a given effort.

The fact that the terms of trade do change makes it more difficult to identify the other factors explaining growth, technological change for a start. The contribution of technological progress is generally measured by Solow residuals, but this is clearly inappropriate in the case of an open economy subject to terms-of-trade shocks. Solow residuals are typically obtained from a one-output two-input Cobb-Douglas representation of the technology. Not only is this measure unsatisfactory because it is based on a rather antiquated functional form (it would be much preferable to use a flexible functional form instead) and because it aggre-

[1] Much of that interest has focused on the performance of South-East Asian nations; see Pack and Page (1994), and Young (1994a, 1994b), for instance.

gates all outputs, but by abstracting from imports and exports, it is obviously incapable of incorporating terms-of-trade effects. Much of the recent empirical work on growth has been based on the Cobb-Douglas framework, at least implicitly so. Thus, Mankiw, Romer and Weil (1992) explicitly use the Cobb-Douglas functional form, whereas Young (1994a, 1994b) measures total factor productivity growth by the difference between the growth rate of output per worker and of a constant proportion of the growth rate of the capital stock per worker.

Undoubtedly, much of growth can be explained by increases in domestic factor endowments. Australia, being an immigration country and having a relatively young population by OECD standards, has seen its labour force increase substantially during the post-war period. Moreover, the rapid pace of investment has led to significant increases in the Australian capital stock. The contribution of labour and capital in explaining overall growth can, however, only be assessed if the technological-change and terms-of-trade effects have been correctly accounted for.

The purpose of this paper is to sort out these effects, and to do so within a formal model of aggregate production. That is, we want to assess the contribution of each one of the major factors explaining Australian nominal GDP growth: technological change, movements in the terms of trade, increases in the endowments of labour and capital, and changes in domestic output prices. We will use both the parametric and the nonparametric growth accounting techniques introduced by Kohli (1990). Both have a solid theoretical foundation, being based on the GNP (or GDP) function approach to modeling the production sector of an open economy; see Kohli (1978, 1991) and Woodland (1982).

The focus of this paper is on *nominal* — rather than *real* — GDP. There are two reasons for this. First, nominal GDP growth is a very broad measure of a country's economic performance since it includes quantity changes as well as price changes; it turns out that our framework is equally well suited to explain the contribution of real variables and of prices. Second, in some ways, nominal GDP is a less controversial concept than real GDP. Indeed, real GDP is a poor measure of real activity. It is basically a direct Laspeyres quantity index, and it is exact for very restrictive functional forms only. Just like we have argued earlier that flexible functional forms are to be preferred over nonflexible ones, one must favour superlative indexes over Laspeyres or Paasche indexes.[2] As shown by Kohli (1983), real GDP does a particularly poor job at accounting for terms-of-trade changes. This is why we prefer to bypass real GDP altogether in this paper.

The paper proceeds as follows. In the next section, we give a brief description of the aggregate technology and of the country's GDP function. Section 3 is devoted to the index number approach to growth accounting, whereas Section 4 deals with the econometric approach. One of the main advantages of the econometric approach is that it makes it possible to decompose the technological residual into secular and random components: Section 5 looks at different ways of achieving the same result with the index number residual. Section 6 concludes.

2 Description of the Aggregate Technology

We treat the endowments of labour (L) and capital (K) as fixed, and consider the prices of imports and outputs as given. Imports (M) are treated as a negative output; the other output components are: consumption goods (C), investment goods (I), government purchases (G), and exports (X). Input and output quantity vectors, measured at time t, are denoted $\mathbf{x}_t \equiv [x_{jt}], j \in \{L, K\}$, and $\mathbf{y}_t \equiv [y_{it}], i \in \{C, I, G, M, X\}$, respectively. The corresponding price vectors are $\mathbf{w}_t \equiv [w_{jt}]$ and $\mathbf{p}_t \equiv [p_{it}]$. We assume that the technology is convex, and that it exhibits constant returns to scale and free disposals. It can be represented by the following GDP function:[3]

$$\pi = \pi(\mathbf{p}_t, \mathbf{x}_t, t) \equiv \max_{\mathbf{y}_t}\{\mathbf{p}_t'\mathbf{y}_t : (\mathbf{y}_t, \mathbf{x}_t) \in T_t\}, \tag{1}$$

where T_t is the production possibilities set at time t. The Translog functional form is well suited to represent the GDP function; omitting the time subscript, it is as follows:[4]

$$\ln \pi \quad = \quad \alpha_0 + \sum \alpha_i \ln p_i + \sum \beta_j \ln x_j + \frac{1}{2}\sum\sum \gamma_{ih} \ln p_i \ln p_h +$$

[2] The concept of *superlative* indexes has been introduced by Diewert (1976).

[3] See Kohli (1978, 1991) and Woodland (1982) for details.

[4] See Christensen, Jorgenson and Lau (1973) and Diewert (1974). The last two terms ensure that the GDP function is fully flexible with respect to technological change, to use the terminology of Diewert and Wales (1992).

$$
\begin{aligned}
&\frac{1}{2}\sum\sum \phi_{jk}\ln x_j \ln x_k + \sum\sum \delta_{ij}\ln p_i \ln x_j + \\
&\sum \delta_{iT}\ln p_i t + \sum \phi_{jT}\ln x_j t + \beta_T t + \frac{1}{2}\phi_{TT}t^2, \qquad (2)\\
&\qquad i,h \,\epsilon\, \{M,X,I,G,C\};\ j,k \,\epsilon\, \{L,K\},
\end{aligned}
$$

where $\sum \alpha_i = 1$, $\sum \beta_j = 1$, $\gamma_{ih} = \gamma_{hi}$, $\phi_{jk} = \phi_{kj}$, $\sum \gamma_{ih} = 0$, $\sum \phi_{jk} = 0$, $\sum_i \delta_{ij} = 0$, $\sum_j \delta_{ij} = 0$, $\sum \delta_{iT} = 0$, and $\sum \phi_{jT} = 0$. It is well known that, under competitive conditions, differentiation of the GDP function with respect to output prices yields the import demand and output supply functions, while differentiation with respect to factor quantities produces the inverse input demand functions.[5] In terms of shares:

$$
\begin{aligned}
s_i &= \alpha_i + \sum \gamma_{ih}\ln p_h + \sum \delta_{ij}\ln x_j + \delta_{iT}t, \qquad i \,\epsilon\, \{M,X,I,G,C\} \qquad (3)\\
s_j &= \beta_j + \sum \delta_{ij}\ln p_i + \sum \phi_{jk}\ln x_k + \phi_{jT}t, \qquad j \,\epsilon\, \{L,K\}, \qquad (4)
\end{aligned}
$$

where $s_i \equiv p_i y_i/\pi$ and $s_j \equiv w_j x_j/\pi$ are the GDP shares of output i and factor j, respectively.

3 Accounting for Growth: An Index Number Approach

The purpose of this section is to show how, assuming that the GDP function is Translog, one can get a *complete* and *exact* decomposition of nominal GDP growth. The four causes of GDP growth which are identified are: i) technological change, ii) terms-of-trade changes, iii) changes in domestic factor endowments, and iv) changes in domestic prices. This exercise entirely relies on an index number technique, and it only requires knowledge of the data. The main result of this section is summarized by expression (17) below.

Following Diewert and Morrison (1986), we begin by defining the following *productivity index* to capture the GDP effect of the change in technology between time $t-1$ and time t:

$$
R_{t,t-1} \equiv \left[\frac{\pi(\mathbf{p}_{t-1},\mathbf{x}_{t-1},t)}{\pi(\mathbf{p}_{t-1},\mathbf{x}_{t-1},t-1)}\ \frac{\pi(\mathbf{p}_t,\mathbf{x}_t,t)}{\pi(\mathbf{p}_t,\mathbf{x}_t,t-1)}\right]^{\frac{1}{2}}. \qquad (5)
$$

[5] See Kohli (1991), for instance.

$R_{t,t-1}$ can be interpreted as the geometric mean of Laspeyres and Paasche productivity indices; it thus has the Fisher form, so to speak. $\pi(\cdot)$ is generally unknown, and hence $R_{t,t-1}$ cannot be obtained from (5) directly. However, it turns out that *if the GDP function has the Translog form*, i.e. if $\pi(\cdot)$ is given by (2), $R_{t,t-1}$ can be calculated from the data alone in the following way (Diewert and Morrison, 1986):

$$R_{t,t-1} = \frac{\Gamma_{t,t-1}}{P_{t,t-1} \cdot X_{t,t-1}}, \tag{6}$$

where

$$\Gamma_{t,t-1} \equiv \frac{\sum p_{it} y_{it}}{\sum p_{it-1} y_{it-1}} \tag{7}$$

$$P_{t,t-1} \equiv \exp\left[\sum \frac{1}{2}(s_{it} + s_{it-1}) \ln \frac{p_{it}}{p_{it-1}}\right] \tag{8}$$

$$X_{t,t-1} \equiv \exp\left[\sum \frac{1}{2}(s_{jt} + s_{jt-1}) \ln \frac{x_{jt}}{x_{jt-1}}\right]. \tag{9}$$

$\Gamma_{t,t-1}$ is (one plus) the rate of increase in nominal GDP between times $t-1$ and t; $P_{t,t-1}$ is the Törnqvist *output price index*, and $X_{t,t-1}$ is the Törnqvist *fixed input quantity index*.

Expressions (8) and (9) indicate the price or the quantity changes for two consecutive periods; the Törnqvist chain indexes can be obtained by compounding the individual elements:

$$p_t \equiv P_{t,t-1} \cdot p_{t-1}$$

$$x_t \equiv X_{t,t-1} \cdot x_{t-1}.$$

The initial values of p_t and x_t can be set to some arbitrary positive numbers, generally chosen to be one. Similarly, $R_{t,t-1}$ can be compounded to yield the *total factor productivity index*, τ:

$$\tau_t \equiv R_{t,t-1} \cdot \tau_{t-1}. \tag{10}$$

Next, consider the GDP effect of a change in the terms of trade between times $t-1$ and t. Following Diewert and Morrison (1986), we can define the following *terms-of-trade GDP adjustment index*, $A_{t,t-1}$, devised to capture the GDP effect of a change in the terms of trade between time $t-1$ and time t:

$$A_{t,t-1} \equiv \left[\frac{\pi(p_{Mt}, p_{Xt}, \mathbf{p}_{Nt-1}, \mathbf{x}_{t-1}, t-1)}{\pi(p_{Mt-1}, p_{Xt-1}, \mathbf{p}_{Nt-1}, \mathbf{x}_{t-1}, t-1)} \frac{\pi(p_{Mt}, p_{Xt}, \mathbf{p}_{Nt}, \mathbf{x}_t, t)}{\pi(p_{Mt-1}, p_{Xt-1}, \mathbf{p}_{Nt}, \mathbf{x}_t, t)}\right]^{\frac{1}{2}}, \tag{11}$$

where $\mathbf{p}_N$ is the vector of domestic prices: $\mathbf{p}_N \equiv [p_I, p_G, p_C]'$. $A_{t,t-1}$ can also be interpreted as the geometric mean of Laspeyres and Paasche indices. Again, since $\pi(\cdot)$ is generally not known, $A_{t,t-1}$ cannot be computed from (11) directly. However, as long as the GDP function has the Translog form, $A_{t,t-1}$ can be calculated from knowledge of the data alone (Diewert and Morrison, 1986):

$$A_{t,t-1} = \exp\left[\frac{1}{2}(s_{Mt} + s_{Mt-1})\ln\frac{p_{Mt}}{p_{Mt-1}} + \frac{1}{2}(s_{Xt} + s_{Xt-1})\ln\frac{p_{Xt}}{p_{Xt-1}}\right]. \qquad (12)$$

Note that (12) is similar to a Törnqvist price index, except that the sum of the weights — the GDP shares of imports and exports — would normally be much less than unity.[6]

The productivity and the terms-of-trade indexes are defined for given prices of nontraded goods, and for given factor endowments; they measure the change in GDP that is attributable to technological progress and to the change in the terms of trade exclusively. A change in factor endowments is obviously liable to affect GDP as well. To assess the contribution of factor j, Kohli (1990) proposed the following *input quantity effect*:[7]

$$X_{j\,t,t-1} \equiv \left[\frac{\pi(\mathbf{p}_{t-1}, x_{jt}, x_{kt-1}, t-1)}{\pi(\mathbf{p}_{t-1}, x_{jt-1}, x_{kt-1}, t-1)}\,\frac{\pi(\mathbf{p}_t, x_{jt}, x_{kt}, t)}{\pi(\mathbf{p}_t, x_{jt-1}, x_{kt}, t)}\right]^{\frac{1}{2}}, \qquad (13)$$

$$j, k \in \{L, K\}, j \neq k.$$

$X_{j\,t,t-1}$ measures the contribution of factor j to GDP growth between times $t-1$ and t. Assuming once again that $\pi(\cdot)$ is given by (2), it can be shown that $X_{j\,t,t-1}$ can be measured as follows:[8]

$$X_{j\,t,t-1} \equiv \exp\left[\frac{1}{2}(s_{jt} + s_{jt-1})\ln\frac{x_{jt}}{x_{jt-1}}\right], \qquad j \in \{L, K\}. \qquad (14)$$

Finally, we can evaluate the GDP contribution of nontraded good prices. Kohli (1990) introduced the following *nontraded good price effect*:[9]

$$P_{N\,t,t-1} \equiv \left[\frac{\pi(p_{Mt-1}, p_{Xt-1}, \mathbf{p}_{Nt}, \mathbf{x}_{t-1}, t-1)}{\pi(p_{Mt-1}, p_{Xt-1}, \mathbf{p}_{Nt-1}, \mathbf{x}_{t-1}, t-1)}\,\frac{\pi(p_{Mt}, p_{Xt}, \mathbf{p}_{Nt}, \mathbf{x}_t, t)}{\pi(p_{Mt}, p_{Xt}, \mathbf{p}_{Nt-1}, \mathbf{x}_t, t)}\right]^{\frac{1}{2}}. \qquad (15)$$

[6] If trade were balanced, the weights would add up to zero.

[7] Morrison and Diewert (1990) defined a similar effect, but in terms of the sales function.

[8] See Kohli (1990).

[9] A similar effect, but defined in terms of the sales function, was proposed by Morrison and Diewert (1990).

$P_{N\,t,t-1}$ measures the growth in GDP that is due to domestic price changes only. While (15) is not very helpful to measure $P_{N\,t,t-1}$ since $\pi(\cdot)$ is generally not known, it can be shown that if the GDP function has the Translog form, $P_{N\,t,t-1}$ can be calculated as follows:[10]

$$
\begin{aligned}
P_{N\,t,t-1} \quad = \quad & \exp\left[\frac{1}{2}(s_{It}+s_{It-1})\ln\frac{p_{It}}{p_{It-1}}+\frac{1}{2}(s_{Gt}+s_{Gt-1})\ln\frac{p_{Gt}}{p_{Gt-1}}+\right. \\
& \left.\frac{1}{2}(s_{Ct}+s_{Ct-1})\ln\frac{p_{Ct}}{p_{Ct-1}}\right]. \qquad (16)
\end{aligned}
$$

Making use of (6)–(9), (12), (14) and (16), finally, it turns out that the following gives a complete and exact decomposition of GDP growth in the Translog case (Kohli, 1990):

$$\Gamma_{t,t-1} = R_{t,t-1} \cdot A_{t,t-1} \cdot X_{L\,t,t-1} \cdot X_{K\,t,t-1} \cdot P_{N\,t,t-1}. \qquad (17)$$

The product of the first two terms on the right hand side make up Diewert and Morrison's welfare change index. Multiplying this by the labour and capital quantity effects, one obtains the change in GDP after one allows for changes in factor endowments; this can be interpreted as the change in net real output, or, alternatively, since none of the domestic prices has yet been allowed to vary, the change in real national income. Finally, multiplying by the nontraded good price effect, we get nominal GDP growth.

We report in Table 1 estimates of the decomposition of Australian GDP growth based on (17), using annual data for the period 1960–1992.[11] Geometric averages for the entire sample period are shown at the bottom of the table.

Focusing first on the figures for the entire period, we find that nominal GDP has increased at an average annual rate of 10.7%, approximately. Increases in domestic prices account for about two thirds of the increase in GDP. Dividing $\Gamma_{t,t-1}$ by $P_{N\,t,t-1}$, we can calculate that the average growth rate of real net output (i.e. real national income) is about 3.7% per annum. About half of this is explained by capital accumulation, one third by the growth in employment, and one sixth by technological progress. The terms-of-trade effect has been unfavourable on average, but rather weak:just over one tenth of a percentage point per year. Although

[10] See Kohli (1990).
[11] See the Appendix for a description of the data.

this still adds up to over 4% of GDP over the entire sample period, one of the findings of this paper thus is that the Australian terms-of-trade effect is smaller than one might have expected it, considering Australia's reliance on exports of raw materials and farm products.[12]

Considering next the individual effects, we first see that the rate of technological change has been very volatile during the sample period. Thus, the rate of technological change has been as high as 7.0% (in 1983), and as low as minus 3.0% (in 1965).

The direct effect of changes in the terms of trade on GDP is shown in the second column of Table 1 by the estimates of $A_{t,t-1}$. While small on average, this effect has been far from trivial. At times, it has contributed very substantially to GDP growth, like in 1972 when it added 2.8% to GDP growth, and in 1988 when it added 2.4%. In 1985, on the other hand, the adverse movement in the terms of trade shaved 2.1% off GDP growth; the following year, growth was reduced by an additional 1.6%. Thus, year-to-year real growth estimates could be considerably distorted by failure to take the terms-of-trade effect into consideration.

The contribution of employment has been remarkably strong for most of the sample period, except for the mid-seventies, the early eighties, and the early nineties. In 1972, for instance, the employment effect added 3.6% to GDP growth, which is quite astonishing. It is important to stress that $X_{L\,t,t-1}$ does not measure the growth in employment, but rather the contribution of labour growth to GDP growth. It reflects both the increase in the endowment of labour and changes in the GDP share of labour. As indicated by (4), these changes in the labour share are mostly due to technological change, to movements in relative factor endowments, and changes in relative output prices.[13]

The same is true for the capital quantity effect which is reported in the next column. Capital accumulation is by far the main engine of real economic growth, although its role has been weakening in recent years. This is due to a large extent to a slowdown in the rate of capital formation; it is also partly explained by a

[12] Kohli (1996), looking at OECD member countries, reports negative effects in excess of one percent annually for Greece, Ireland, Portugal, and Turkey; the largest positive effects are found for Canada, Germany, and Switzerland.

[13] This strong component is in sharp contrast with the situation in most European countries where the contribution of employment has generally been *negative*; see Kohli (1996).

reduction in the GDP share of capital.

Multiplying the indexes of the first four columns of the table by one another, we get the real net output. As suggested earlier, this index (not shown here) is largely dominated by the capital quantity effect. Real net output growth was particularly high during the sixties, topping 9% in 1963 and 1968! It has been positive in all but two years, 1982 and 1990.

Looking at the domestic price effect, finally, we see that it is rather substantial and volatile, more often than not dominating the movements of nominal GDP. The effect was largest in 1974 when it almost reached 20%. It was weakest at both ends of our sample. It must be emphasized that, strictly speaking, $P_{N\,t,t-1}$ is not a price index. As shown by (16), the weights used to compute $P_{N\,t,t-1}$ normally do not add up to unity. However, if the trade account is close to equilibrium, $P_{N\,t,t-1}$ comes close to a Törnqvist index of domestic prices.

Our results can be summarized graphically. The total decomposition of nominal GDP growth is shown in Figure 1. The dashed line at the bottom of the graph shows the contribution of employment growth. The second line is obtained by adding to it the contribution of capital accumulation. We next add the contribution of the terms-of-trade movements, advances in the technology, and, finally, domestic price increases. One observes that most of Australian GDP growth is explained by price increases. In order to get a more precise picture, we focus, in Figure 2, on real variables. The fat line, which summarizes the contribution of employment growth, capital accumulation, terms-of-trade changes, and technological change, can be interpreted as the path of real net output. It is clearly visible that the terms of trade have not contributed much to GDP growth on average. On the contrary, in the late 1980's, this component has rather been a drag on income growth.[14]

4 Accounting for Growth: Parametric Estimates

One attractive feature of the GDP growth decomposition presented in the previous section is that, being based on an index number approach, it depends exclusively

[14] In contrast, in countries such as Canada or Switzerland whose terms of trade have improved, this componenent has contributed significantly to economic growth; see Kohli (1996).

on the data. In particular, no detailed knowledge of $\pi(\cdot)$ is needed, as long as one knows that technology can indeed be represented by a Translog GDP function similar to (2). Nevertheless, econometric estimates of the parameters of (2) can in principle be obtained. This paves the way to an econometric approach to the decomposition of GDP growth.

The reader might of course wonder, why bother with econometric estimates when it is possible to rely on the index number technique. The index number approach is undoubtedly simpler, and less controversial since it does not require the choice of a stochastic specification and of an estimation technique. On the other hand, the econometric approach can yield additional results. Thus, it will produce a set of price and quantity elasticities which cannot be obtained otherwise. More to the point, however, the econometric approach will yield a decomposition of GDP growth that is based on profit maximizing and cost minimizing shares — rather than on observed ones — and thus it will abstract from errors in optimization. More importantly still, it will make it possible to decompose the technological residual into a secular component and a transitory one. While we will explore ways, in the next section, of achieving a similar result on the basis of the index number estimates, the decomposition presented here is more general — and indeed more *flexible* — since it will also take into account changes in relative prices and changes in relative factor endowments.

We have estimated GDP function (2) together with the system of derived output supply and inverse input demand equations — equations (3) and (4). For this purpose, we have used the algorithm of Berndt, Hall, Hall and Hausman (1974) as implemented in TSP, Version 4.2A; this is essentially a nonlinear version of the iterative Zellner method. Since the input shares as well as the output shares add up to unity, two equations had to be left out for estimation purposes, but the results do not depend on which equations are left out.

Initial experiments revealed that the estimated GDP function failed to satisfy the required convexity conditions. This is not unusual in a model of this size. Convexity in prices was therefore imposed *locally.* This was done for 1980, using the reparameterization of Wiley, Schmidt, and Bramble (1973), as proposed by Diewert and Wales (1987). The resulting parameter estimates, together with their asymptotic t-values, are reported in Table 2. Unfortunately, this method does not guarantee that the estimated function will satisfy the curvature conditions over the entire sample. Indeed, while we find that all own price elasticities of import demand and output supply exhibit the correct signs for all observations, inspection of the principal minors of higher order reveals some violations of the convexity conditions for some observations. However, since our prime concern is the decompostion of GDP growth — for this exercise only the estimated GDP shares of the various inputs and outputs are needed — the curvature conditions are of lesser importance here. For information purposes we show in Table 3 estimates of all price and quantity elasticities, as defined in Kohli (1991); we also show the time semi-elasticities of output supplies and inverse input demands, as well as the impact of changes in prices and factor endowments on the instantaneous rate of technological change ($\mu \equiv \partial \ln \pi(\cdot)/\partial t$), as defined in Kohli (1994). These estimates are for 1992, the last year of our sample, and they fully satisfy all required regularity conditions.

The parameter estimates shown in Table 2 can now be used to obtain a *parametric* decompostion of GDP growth. For instance, we can calculate $A_{t,t-1}$ from (11) directly, without having to use (12). Similarly, we can calculate $X_{Lt,t-1}$, $X_{Kt,t-1}$, and $P_{Nt,t-1}$ directly from (13) and (15), without having to rely on (14) and (16). Not only will this exercise yield a decomposition of GDP growth that abstracts from errors in optimization, but it will also enable us to decompose the technological change index into secular and transitory components.

Since our decomposition of GDP is based on the Translog estimates, rather than on the data directly, it is the fitted, or the potential, value of GDP, rather than the observed one, that we are explaining. Let $\Pi_{t,t-1}$ be defined as (one plus) the rate of growth of potential GDP:

$$\Pi_{t,t-1} = \frac{\pi(\mathbf{p}_t, \mathbf{x}_t, t)}{\pi(\mathbf{p}_{t-1}, \mathbf{x}_{t-1}, t-1)}. \tag{18}$$

The counterpart of (17) therefore is:

$$\Pi_{t,t-1} = S_{t,t-1} \cdot A_{t,t-1} \cdot X_{Lt,t-1} \cdot X_{Kt,t-1} \cdot P_{Nt,t-1}, \tag{19}$$

where the terms on the right-hand side are now calculated from the Translog estimates, rather than from (6), (12), (14) and (16), and where $S_{t,t-1}$ is defined as the *secular* component of technological change. Naturally, $\Pi_{t,t-1} \neq \Gamma_{t,t-1}$ in general. The *unexplained* residual, $U_{t,t-1}$, is defined as:

$$U_{t,t-1} \equiv \frac{\Gamma_{t,t-1}}{\Pi_{t,t-1}}. \tag{20}$$

While the Solow residual has been popularly used as the component driving real business cycle models, and at the center of work on the international propagation of productivity shifts, $U_{t,t-1}$ seems to be a more attractive measure of technological change. It is based on a flexible, multiple-input, multiple-output representation of the aggregate technology, and has been purged of trend/secular shifts of the technology. Therefore, it can be considered as a measure of true productivity "shocks".

Observed GDP growth can therefore be decomposed as follows:

$$\Gamma_{t,t-1} = S_{t,t-1} \cdot U_{t,t-1} \cdot A_{t,t-1} \cdot X_{Lt,t-1} \cdot X_{Kt,t-1} \cdot P_{Nt,t-1}. \tag{21}$$

Before reporting empirical estimates of (21), let us briefly turn to the practical task of computing the indexes from the Translog parameters. Substituting (2) into (5), we get:

$$\ln(S_{t,t-1}) = \frac{1}{2}\Sigma\delta_{iT}\ln(p_{it}p_{it-1}) + \frac{1}{2}\Sigma\phi_{jT}\ln(x_{jt}x_{jt-1}) + \beta_T + \frac{1}{2}\phi_{TT}(2t-1), \tag{22}$$
$$i, h\epsilon\{M, X, I, G, C\}; j, k\epsilon\{L, K\}.$$

Similarly, substituting (2) into (11), (13), and (15), we obtain:

$$\begin{aligned}
\ln(A_{t,t-1}) \;=\;& \frac{1}{2}\Sigma\Sigma\gamma_{ih}[\ln(p_{it})\ln(p_{ht}) - \ln(p_{it-1})\ln(p_{ht-1})] + \\
& \Sigma\ln\left(\frac{p_{it}}{p_{it-1}}\right)[\alpha_i + \frac{1}{2}\Sigma\gamma_{im}\ln(p_{mt}p_{mt-1}) + \\
& \frac{1}{2}\Sigma\delta_{ij}\ln(x_{jt}x_{jt-1}) + \frac{1}{2}\delta_{iT}(2t-1)], \qquad (23)\\
& \qquad i, h\epsilon\{M, X\}; m\epsilon\{I, G, C\}; j\epsilon\{L, K\};\\
\ln(X_{jt,t-1}) \;=\;& \ln\left(\frac{x_{jt}}{x_{jt-1}}\right)[\beta_j + \frac{1}{2}\Sigma\phi_{jk}\ln(x_{kt}x_{kt-1}) + \\
& \frac{1}{2}\Sigma\delta_{ij}\ln(p_{it}p_{it-1}) + \frac{1}{2}\phi_{jT}(2t-1)], \qquad (24)\\
& \qquad i, h\epsilon\{M, X, I, G, C\}; j, k\epsilon\{L, K\};
\end{aligned}$$

$$
\begin{aligned}
\ln(P_{Nt,t-1}) &= \frac{1}{2}\Sigma\Sigma\gamma_{ih}[\ln(p_{it})\ln(p_{ht}) - \ln(p_{it-1})\ln(p_{ht-1})] + \\
&\Sigma \ln\left(\frac{p_{it}}{p_{it-1}}\right)[\alpha_i + \frac{1}{2}\Sigma\gamma_{im}\ln(p_{mt}p_{mt-1}) + \\
&\frac{1}{2}\Sigma\delta_{ij}\ln(x_{jt}x_{jt-1}) + \frac{1}{2}\delta_{iT}(2t-1)], \qquad (25) \\
&\qquad i, h\epsilon\{I, G, C\}; m\epsilon\{M, X\}; j\epsilon\{L, K\}.
\end{aligned}
$$

We report in Table 4 estimates of the decomposition of GDP growth according to (21). Comparing the figures of Table 4 with those of Table 1, one sees that for most components the estimates are very close.[15] This reflects the fact that the fit of the model is quite good; hence, it makes little difference whether we take actual shares or potential shares as a basis for our calculations. However, unlike the nonparametric approach, the Translog estimates allow for the decomposition of technological change into a secular — or expected — term, measured by $S_{t,t-1}$, and a random — or unexpected — term, captured by $U_{t,t-1}$. While the product of these two components comes close to the nonparametric measure of $R_{t,t-1}$ reported in Table 1, the decomposition into these two factors is of considerable interest. Looking at the averages for the entire period, one sees that less than one tenth of one percentage point of GDP growth is unaccounted for by the model, while the secular rate of technological change came close to 0.7%. This rate has actually increased over time, from about 0.4% in the early sixties, to about 0.8% in the early nineties. This measure of technological change is fairly smooth since it does not incorporate the unexplained component ($U_{t,t-1}$). Note, however, that $S_{t,t-1}$ is not simply a function of time: as shown by (22), it also depends on changes in the terms of trade, in factor endowments, and in nontraded good prices. The estimates in the last line of Table 3 show that an improvement in the terms of trade tends to increase the rate of technological change. An increase in capital intensity tends to have the same effect. These effects are distinct from, and in addition to, the direct effect of a change in the terms of trade on GDP growth as measured by $A_{t,t-1}$, or the GDP effect of a change in factor endowments as captured by $X_{L\,t,t-1}$ and $X_{K\,t,t-1}$. As for the unexplained component of GDP growth, we observe that it can be quite important at times. Its (logarithmic) mean is close to zero (-0.00096),

[15] Naturally, the numbers for $\Gamma_{t,t-1}$ are the same in both tables since they are based on observed data; see (7).

but its standard deviation is close to 2% (0.01987).

5 The Decomposition of Technological Change: An Alternative Approach

One major advantage of relying on econometric estimates of the Translog GDP function to account for GDP growth is that this approach yields a decomposition of technological change into secular and unexpected components. Unfortunately, estimation of the GDP function may be problematic. This was underscored in the previous section by the difficulties we encountered when trying to obtain estimates that satisfy the required convexity conditions. We now propose an alternative method that avoids these difficulties. It builds on the *Index Number Approach* of Section 3, and it stems from the observation that technological change estimated by parametric specifications of production technology yield measures which are very close to smoothed nonparametric index number measures (Kohli, 1990; Diewert and Wales, 1992; Fox, 1994).

The series $R_{t,t-1}$, drawn from Table 1, can be smoothed using statistical techniques. The resulting smoothed series can be interpreted as the trend, or secular component, of technological change. This secular component is denoted by $S_{t,t-1}$, and the unexpected component, $U_{t,t-1}$, is defined residually as:

$$U_{t,t-1} \equiv \frac{R_{t,t-1}}{S_{t,t-1}}. \tag{26}$$

The residual index, $U_{t,t-1}$, can be thought of as an unexpected, and transitory, productivity shock, similar to the concept of the Solow residual.

There are many available techniques for smoothing a series of data. A range of smoothers were used and generated similar results. We will just report on three methods.

The first, and simplest one, consists in regressing the first difference of the logarithm of (τ) — the index of total factor productivity as defined by (10) — on time. From (10) we see that this is the same as regressing the logarithm of $R_{t,t-1}$ on time.[16] This approach is consistent, at least in spirit, with the estimation of

[16] A regression of the logarithm of τ on time and time squared was also performed, but

the Translog GDP function by econometric techniques, and it amounts essentially to getting estimates of β_T and ϕ_{TT} from estimating (22). The resulting decomposition of $R_{t,t-1}$ is shown in the second and third columns of Table 5. Comparing these estimates with those in Table 4, one can conclude that this approach yields results which are broadly similar to the ones obtained by estimating the GDP function directly. In particular, we find again that the secular component of technological change is about 0.6–0.7% per annum on average, and that it tends to increase over time, even though the rate of increase is less than the estimation of the GDP function might have led us to believe.[17] Consequently, the unexpected residuals, $U_{t,t-1}$, from the parameteric approach and this smoothing approach are very highly correlated.[18]

One attractive feature of the indirect approach considered here is that one is not confined to simple regression analysis. The results reported in columns 4 and 5 of Table 5 are from employing the widely used Hodrick-Prescott (HP) filter (Hodrick and Prescott, 1980), i.e. the cubic smoothing spline with the smoothing parameter set to 1600 (see Appendix B).[19] We see that there is very little difference between the results from this method and the OLS method. This need not generally be true, but in this case the large smoothing parameter resulted in a very flat smoothed series.

The results reported in columns 6 and 7 of Table 5 are from employing the Super Smoother introduced by Friedman (1984); see Appendix B. The estimates of $S_{t,t-1}$ for this method indicate that the trend of technological change has been more variable than the other methods have suggested. In particular, this method does not result in uniformly increasing estimates. From Table 5, we see that $U_{t,t-1}$ has been important in explaining GDP growth for some years. It has fluctuated throughout the sample, having positive effects for some years and negative effects for others, with the largest negative effect being -3.3% in 1965, and the largest

the regression results were less favourable in terms of the presence of serial correlation. The regression described in the text yielded a Durbin-Watson statistic of 1.90.

[17]Note that the increase in $S_{t,t-1}$, in Table 4, is driven, in part, by the positive point estimate of ϕ_{TT}; judging from the asymptotic t-values reported in Table 2, this estimate is not significantly greater than zero, however.

[18]The correlation coefficient between the two series is 0.99747.

[19]Estimating the smoothing parameter using the cross validation criterion resulted in an estimate equal to 1627.

positive effect being 6.2% for 1983. While the (logarithmic) mean of 0.00019 is small, the standard deviation is 0.01957.

While the low estimates of trend technological change from all these methods, and periods of downward trending technological change from the Super Smoother, may be of concern to policy makers, it is interesting to note that Kohli (1990) found the trend component in technological progress for the United States to have been clearly downward sloping (1949–1987), using the Translog GDP function estimates.

Our results are illustrated graphically in Figure 3. We show the log of the total factor productivity index (TFPI), and the log of the cumulated contribution of the secular component, using the parametric estimate of Table 4. We also show the log of the secular indexes computed from the OLS regression described at the beginning of this section, the Hodrick-Prescott filter and Super Smoother. It certainly seems that the Super Smoother index does a better job at tracking the total factor productivity index.

While this indirect approach suffers from precisely this attribute of being an indirect — or two-step — approach, in view of the similarities between the parametric and non-parametric decompositions of technological change in tables 4 and 5 respectively, we may conclude that the approach described here offers a convenient alternative to the estimation of the GDP function. Also, the indirect approach is clearly much simpler.

6 Concluding Comments

Our results for Australia show that technological change is quite volatile, averaging around 0.6–0.7%. This is not unusual by OECD standards (Kohli, 1996). What is rather exceptional, however, is that the rate of technological progress gives no obvious sign of persistently declining. So, contrary to many other countries, there seems to be no cause for "growth pessimism" in Australia. The terms-of-trade effect is quite volatile too. It is negative on average, but relatively small. This effect has nevertheless cost Australia over 4% of her GDP over the past three decades. The contribution of employment is very vigorous, particularly so by OECD standards. As one might have expected it, the contribution of capital accumulation is substantial. Finally, about half of Australian GDP growth is an illusion, being due to nontraded good price increases.

One of the findings of this paper is that little harm may be done in following a two-stage approach to divide technological change into secular and unexpected (and unexplained) components. While it is important to disentangle these two effects, our results suggest that this can be done in a rather simple and uncontroversial way, by first relying on the index number approach to identify the contributions of the main engines of growth and to isolate the index of total factor productivity, and then by smoothing this index. In principle, the one-step econometric approach would be more elegant and more satisfactory, but the estimation of a fairly large GDP function models (the one estimated here contained two fixed inputs and five variables quantities) can be problematic. This is why we believe that the approach proposed here should prove to be useful for practitioners who have little time for estimating flexible functional forms. While, contrary to (22), it cannot not take into account the effects that changes in the terms of trade, in nontraded good prices, or in domestic factor endowments might have on the rate of technological change, the two-step method yields results which are very similar to the ones obtained by the econometric approach. Moreover, it makes it possible to choose between a wider array of methods for smoothing the technological contribution and it allows for the adoption of fairly sophisticated methods such as the Super Smoother employed in this paper.

Appendix A: Data Description

For the purpose of this study, we use annual data for the period 1960–1992.[20] Current and constant (1985) dollar values of all GDP components are drawn from the OECD national accounts data base. The corresponding deflators are used as price indexes after they have been corrected to take account of indirect taxes and subsidies. Our figures for nominal GDP are therfore at producer prices, rather than at market prices.

The labour income and capital income series are also taken from the OECD national accounts data base. The quantity of labour is obtained by multiplying the OECD index of wage and salary earners by an index of weekly hours worked.

To obtain the quantity of capital services, we use the procedure of Kohli (1982). Thus, we begin by assuming that the flow of capital services is proportional to the beginning-of-period capital stock.[21] This stock is obtained by cumulating real gross investment subject to a constant depreciation rate, δ:

$$x_{Kt} = (1-\delta)x_{Kt-1} + y_{It-1}, \qquad t = -\infty, \ldots, 1992. \tag{27}$$

This can also be written as:

$$x_{Kt} = y_{It-1} + (1-\delta)y_{It-2} + (1-\delta)^2 y_{It-3} + \cdots, \qquad t = -\infty, \ldots, 1992. \tag{28}$$

Next, we assume that *prior to some period* $T \leq 1960$, real investment grew at a constant rate γ:

$$y_{It} = y_{It-1}(1+\gamma), \qquad t = -\infty, \ldots, T. \tag{29}$$

Making use of (29) in (28) valued at time T, we obtain:

$$\begin{aligned} x_{KT} &= \frac{y_{IT}}{1+\gamma}\left[1 + \frac{1-\delta}{1+\gamma} + \left(\frac{1-\delta}{1+\gamma}\right)^2 + \cdots\right] \\ &= \frac{y_{IT}}{1+\gamma}\left[\frac{1}{1-\frac{1-\delta}{1+\gamma}}\right] \\ &= \frac{y_{IT}}{\gamma+\delta}. \end{aligned} \tag{30}$$

For our purposes, we set T to 1948. We extend the OECD real investment series backwards by linking it to a 1948–1960 series obtained from ABS sources. We calculate γ as the average rate of growth of real investment from 1948 to 1960, i.e.

[20] All data are for the fiscal year that starts on July 1st of any given calendar year.

[21] No attempt is made to correct for variations in the rate of capacity utilization.

to the beginning of our sample period. Finally, we set δ to 5%. The resulting 1948 real capital stock is found to be 86.881 billion 1985 dollars. Making use of (27), we obtain the 1960 stock as 221.217 billion 1985 dollars. Naturally, the estimate of the 1948 stock is quite sentitive to the value of γ, but due to the depreciation factor, this is much less true for the estimate of the 1960 stock. The depreciation rate itself has a fairly large impact on the level of the estimated capital stock, but not so on its rate of growth which is what matters for the purpose of this study.

Appendix B: Smoothers

The cubic smoothing spline estimates the function $S_{t,t-1}$ that minimizes the following; subscripts $(t, t-1)$ on R and S are dropped for notational simplicity.

$$\sum_{i=1}^{n}(R^i - S(R^i))^2 + \lambda \int (S''(t))^2 dt. \tag{31}$$

The parameter λ is called the smoothing parameter, which acts to penalize changes in the second order derivatives of the smoothing function. When λ is set to 1600, the cubic smoothing spline is usually known to economists as the Hodrick-Prescott filter (Hodrick and Prescott, 1980).

Using the Super Smoother technique the smooth function, $S_{t,t-1}$, is built pointwise as follows.

1. The k nearest neighbours to some point R^0 define the "span". Observations which lie within this span are said to be within a neighbourhood, $N(R^0)$, of R^0. The choice of the span is discussed below.

2. The largest distance between R^0 and another point in $N(R^0)$ is calculated:

$$\Delta R^0 = max_{N(R^0)}|R^0 - R^i|. \tag{32}$$

3. A tri-cube weight function is used to assign weights to each point in $N(R^0)$:

$$W\left(\frac{|R^0 - R^i|}{\Delta R^0}\right) \tag{33}$$

   where

$$W(u) = \begin{cases} (1-u^3)^3 & \text{for } 0 \leq u < 1 \\ 0 & \text{otherwise.} \end{cases} \tag{34}$$

4. Using these weights, the weighted least squares fit of R^0 on $N(R^0)$ is calculated, and the fitted value is taken to be S^0.

5. This procedure is repeated for each observation.

For a fixed span, the above describes locally weighted regression smoothing. A constant span may be inappropriately restrictive. Super Smoother chooses the span for each observation based on the cross-validation criterion (Schmidt, 1971; Stone, 1974):

$$CV(k) = (1/k) \sum_{i=1}^{k} [R^i - S^{-i}(R^i|k)]^2, \tag{35}$$

where S^{-i} denotes the smoothed value of R^i calculated by dropping R^i and using the R_j in the neighbourhood $N(R^0)$ of span k as predictors of R^i. The span which minimizes $CV(k)$ is selected for each R^i.[22]

[22] All smoothing described in this Appendix was performed using S-PLUS (Statistical Sciences, 1995). Due to an end point problem (the smooth trying to fit points near the end of the sample too closely) the option "bass=9" was specified to control the low frequency emphasis and produce a smoother fit at the end of the sample (Friedman, 1984).

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Table 1: Australian GDP Growth Accounting — Nonparametric Estimates
(yearly rates and geometric averages)

	$R_{t,t-1}$	$A_{t,t-1}$	$X_{L\,t,t-1}$	$X_{K\,t,t-1}$	$P_{N\,t,t-1}$	$\Gamma_{t,t-1}$
1961	0.97909	1.00199	1.02363	1.02100	1.00612	1.03158
1962	1.01672	1.00357	1.01427	1.02761	1.01572	1.08020
1963	1.03076	1.01732	1.01429	1.02846	1.01879	1.11442
1964	0.99858	0.99177	1.02785	1.03507	1.04390	1.09990
1965	0.97018	0.99964	1.02290	1.02884	1.02529	1.04646
1966	1.00733	0.99888	1.03168	1.02808	1.03727	1.10699
1967	0.99572	0.99321	1.01671	1.02516	1.03496	1.06683
1968	1.03036	1.00424	1.02223	1.03063	1.03567	1.12902
1969	1.01240	1.00280	1.01936	1.02747	1.04231	1.10831
1970	1.00658	0.98200	1.02359	1.02582	1.06553	1.10592
1971	1.01638	0.99470	1.01383	1.02190	1.06684	1.11745
1972	0.98680	1.02763	1.03631	1.01991	1.06567	1.14219
1973	0.99080	1.01077	1.02187	1.02312	1.13865	1.19220
1974	1.00250	0.98776	1.00344	1.01744	1.19450	1.20760
1975	1.03323	0.99180	0.98322	1.01455	1.14823	1.17374
1976	1.01787	0.99545	0.99605	1.01599	1.11627	1.14459
1977	1.00043	0.98441	0.99958	1.01184	1.09507	1.09077
1978	1.03807	1.00329	0.99411	1.01587	1.07945	1.13535
1979	0.99263	1.00534	1.01840	1.01475	1.09301	1.12720
1980	1.00063	0.99811	1.01182	1.01604	1.11018	1.13988
1981	0.98637	0.99625	1.01679	1.01711	1.10896	1.12699
1982	1.00450	0.99546	0.97455	1.00866	1.09829	1.07954
1983	1.07030	1.00333	0.97794	1.01193	1.06492	1.13169
1984	1.00464	0.99441	1.03268	1.01395	1.05583	1.10448
1985	0.99891	0.97855	1.02681	1.01428	1.09204	1.11172
1986	0.99795	0.98435	1.01983	1.01125	1.08582	1.10001
1987	1.01415	1.01511	1.02165	1.01304	1.05354	1.12252
1988	0.99555	1.02378	1.03115	1.01830	1.06785	1.14282
1989	0.98394	0.99748	1.02970	1.01661	1.06121	1.09029
1990	0.97991	0.99035	1.00983	1.00936	1.04059	1.02933
1991	1.02172	0.99392	0.98181	1.00596	1.02252	1.02556
1992	1.01843	0.99345	0.99974	1.00686	1.01590	1.03462
1961-92	1.00616	0.99872	1.01291	1.01862	1.06795	1.10727

Table 1, continued

Explanations:

$R_{t,t-1}$:	index of technological change
$A_{t,t-1}$:	terms-of-trade adjustment index
$X_{L\,t,t-1}$:	labor quantity effect
$X_{K\,t,t-1}$:	capital quantity effect
$P_{N\,t,t-1}$:	domestic price effect
$\Gamma_{t,t-1}$:	nominal GDP growth index (actual data).

Table 2: Translog GDP Function — Parameter Estimates
(t-values in parentheses)

α_0	11.732 (2678.)	γ_{IG}	-0.01240 (-0.47)
α_M	-0.19361 (-48.84)	γ_{GG}	0.23926 (18.92)
α_X	0.19704 (60.14)	ϕ_{LL}	-0.39074 (-8.42)
α_I	0.21512 (29.23)	δ_{ML}	-0.09952 (-3.74)
α_G	0.19797 (93.46)	δ_{XL}	0.05424 (2.18)
β_L	0.60522 (112.1)	δ_{IL}	0.22365 (4.38)
γ_{MM}	-0.13702 (-4.65)	δ_{GL}	0.06625 (3.13)
γ_{MX}	0.02516 (1.17)	δ_{MT}	-0.00419 (-4.81)
γ_{MI}	-0.08008 (-1.74)	δ_{XT}	0.00532 (6.35)
γ_{MG}	0.07411 (4.77)	δ_{IT}	0.00223 (1.34)
γ_{XX}	0.21178 (11.31)	δ_{GT}	0.00131 (2.15)
γ_{XI}	-0.09287 (-2.08)	ϕ_{LT}	-0.00925 (-6.42)
γ_{XG}	-0.10279 (-10.12)	β_T	0.00831 (18.19)
γ_{II}	0.41382 (3.39)	ϕ_{TT}	-0.00003 (-0.59)

Table 3: Translog GDP Function — 1992 Price and Quantity Elasticities

$$\varepsilon_{mn} \equiv \partial \ln z_m / \partial \ln v_n,$$

$$z_m \epsilon \{y_M, y_X, y_I, y_G, y_C, w_L, w_K, e^{\mu}\},\ v_n \epsilon \{p_M, p_X, p_I, p_G, p_C, x_L, x_K, e^t\},$$
$$\mu \equiv \partial \ln \pi(\cdot)/\partial t$$

	$n = M$	$n = X$	$n = I$	$n = G$	$n = C$	$n = L$	$n = K$	$n = T$
ε_{Mn}	-0.566	0.075	0.611	-0.140	0.019	1.002	-0.002	0.028
ε_{Xn}	-0.082	0.285	-0.245	-0.320	0.362	0.812	0.188	0.036
ε_{In}	-0.555	-0.204	1.006	0.156	-0.404	1.491	-0.491	0.018
ε_{Gn}	0.142	-0.297	0.174	0.352	-0.371	0.849	0.151	0.014
ε_{Cn}	-0.007	0.122	-0.164	-0.135	0.184	0.107	0.893	-0.000
ε_{Ln}	-0.399	0.296	0.653	0.334	0.116	-1.201	1.201	-0.009
ε_{Kn}	0.001	0.078	-0.245	0.068	1.098	1.369	-1.369	0.028
ε_{Tn}	-0.004	0.005	0.002	0.001	-0.005	-0.009	0.009	-0.000

Table 4: Australian GDP Growth Accounting — Parametric Estimates
(yearly rates and geometric averages)

	$S_{t,t-1}$	$U_{t,t-1}$	$A_{t,t-1}$	$X_{L\,t,t-1}$	$X_{K\,t,t-1}$	$P_{N\,t,t-1}$	$\Gamma_{t,t-1}$
1961	1.00376	0.97555	1.00200	1.02321	1.02147	1.00592	1.03158
1962	1.00401	1.01232	1.00329	1.01416	1.02789	1.01618	1.08020
1963	1.00462	1.02663	1.01739	1.01470	1.02748	1.01868	1.11442
1964	1.00501	0.99455	0.99185	1.02902	1.03330	1.04342	1.09990
1965	1.00508	0.96565	0.99998	1.02329	1.02821	1.02477	1.04646
1966	1.00518	1.00282	0.99894	1.03180	1.02794	1.03652	1.10699
1967	1.00519	0.99100	0.99327	1.01665	1.02528	1.03441	1.06683
1968	1.00536	1.02513	1.00432	1.02221	1.03067	1.03531	1.12902
1969	1.00570	1.00680	1.00293	1.01953	1.02715	1.04218	1.10831
1970	1.00568	0.99960	0.98205	1.02308	1.02660	1.06659	1.10592
1971	1.00553	1.00880	0.99360	1.01323	1.02331	1.06931	1.11745
1972	1.00593	0.98158	1.02426	1.03512	1.02082	1.06879	1.14219
1973	1.00656	0.98356	1.00922	1.02128	1.02400	1.14098	1.19220
1974	1.00692	0.99360	0.98929	1.00325	1.01898	1.19348	1.20760
1975	1.00718	1.02318	0.99129	0.98412	1.01590	1.14923	1.17374
1976	1.00750	1.00995	0.99430	0.99612	1.01650	1.11730	1.14459
1977	1.00755	0.99232	0.98402	0.99958	1.01211	1.09588	1.09077
1978	1.00771	1.03061	1.00261	0.99405	1.01560	1.08004	1.13535
1979	1.00808	0.98487	1.00515	1.01917	1.01389	1.09310	1.12720
1980	1.00827	0.99340	0.99889	1.01219	1.01533	1.10859	1.13988
1981	1.00836	0.98006	0.99699	1.01700	1.01678	1.10613	1.12699
1982	1.00863	0.99607	0.99720	0.97453	1.00865	1.09622	1.07954
1983	1.00917	1.06262	1.00389	0.97700	1.01114	1.06413	1.13169
1984	1.00931	0.99379	0.99589	1.03513	1.01251	1.05495	1.10448
1985	1.00889	0.98985	0.98086	1.02809	1.01334	1.08940	1.11172
1986	1.00842	0.98958	0.98417	1.02048	1.01075	1.08589	1.10001
1987	1.00828	1.00516	1.01476	1.02221	1.01259	1.05448	1.12252
1988	1.00847	0.98614	1.02441	1.03197	1.01770	1.06811	1.14282
1989	1.00846	0.97594	0.99805	1.02968	1.01663	1.06034	1.09029
1990	1.00816	0.97233	0.99008	1.00936	1.00995	1.04038	1.02933
1991	1.00809	1.01149	0.99429	0.98291	1.00645	1.02254	1.02556
1992	1.00817	1.01056	0.99270	0.99975	1.00742	1.01571	1.03462
1961-92	1.00697	0.99904	0.99875	1.01311	1.01861	1.06789	1.10727

Table 4, continued

Explanations:

$S_{t,t-1}$:	index of technological change, secular component
$U_{t,t-1}$:	index of technological change, unexplained component
$A_{t,t-1}$:	terms-of-trade adjustment index
$X_{L\,t,t-1}$:	labor quantity effect
$X_{K\,t,t-1}$:	capital quantity effect
$P_{N\,t,t-1}$:	domestic price effect
$\Gamma_{t,t-1}$:	nominal GDP growth index (actual data).

Table 5: Decomposition of Technological Change
(yearly rates and geometric averages)

		OLS		*HP Filter*		*Super Smoother*	
	$R_{t,t-1}$	$S_{t,t-1}$	$U_{t,t-1}$	$S_{t,t-1}$	$U_{t,t-1}$	$S_{t,t-1}$	$U_{t,t-1}$
1961	0.97909	1.00489	0.97433	1.00507	0.97415	1.00069	0.97841
1962	1.01672	1.00497	1.01169	1.00515	1.01151	1.00131	1.01539
1963	1.03076	1.00505	1.02558	1.00523	1.02539	1.00193	1.02877
1964	0.99858	1.00514	0.99348	1.00532	0.99330	1.00255	0.99604
1965	0.97018	1.00522	0.96514	1.00540	0.96497	1.00317	0.96712
1966	1.00733	1.00530	1.00201	1.00548	1.00184	1.00378	1.00353
1967	0.99572	1.00538	0.99039	1.00557	0.99021	1.00440	0.99136
1968	1.03036	1.00546	1.02476	1.00565	1.02457	1.00559	1.02464
1969	1.01240	1.00555	1.00682	1.00573	1.00663	1.00636	1.00600
1970	1.00658	1.00563	1.00095	1.00582	1.00076	1.00667	0.99991
1971	1.01638	1.00571	1.01061	1.00590	1.01042	1.00670	1.00961
1972	0.98680	1.00579	0.98112	1.00598	0.98093	1.00702	0.97992
1973	0.99080	1.00587	0.98501	1.00607	0.98483	1.00738	0.98354
1974	1.00250	1.00596	0.99656	1.00615	0.99637	1.00813	0.99441
1975	1.03323	1.00604	1.02703	1.00623	1.02683	1.00887	1.02415
1976	1.01787	1.00612	1.01168	1.00632	1.01148	1.00958	1.00821
1977	1.00043	1.00620	0.99426	1.00640	0.99407	1.00997	0.99055
1978	1.03807	1.00628	1.03159	1.00648	1.03138	1.00938	1.02842
1979	0.99263	1.00637	0.98635	1.00657	0.98616	1.00865	0.98411
1980	1.00063	1.00645	0.99422	1.00665	0.99402	1.00817	0.99252
1981	0.98637	1.00653	0.97997	1.00673	0.97977	1.00807	0.97847
1982	1.00450	1.00661	0.99790	1.00681	0.99770	1.00772	0.99680
1983	1.07030	1.00669	1.06318	1.00690	1.06297	1.00748	1.06235
1984	1.00464	1.00678	0.99788	1.00698	0.99767	1.00718	0.99748
1985	0.99891	1.00686	0.99211	1.00706	0.99190	1.00665	0.99232
1986	0.99795	1.00694	0.99107	1.00715	0.99087	1.00573	0.99226
1987	1.01415	1.00702	1.00708	1.00723	1.00687	1.00495	1.00915
1988	0.99555	1.00711	0.98853	1.00731	0.98832	1.00433	0.99125
1989	0.98394	1.00719	0.97692	1.00740	0.97672	1.00398	0.98004
1990	0.97991	1.00727	0.97284	1.00748	0.97263	1.00430	0.97572
1991	1.02172	1.00735	1.01426	1.00756	1.01405	1.00486	1.01677
1992	1.01843	1.00743	1.01092	1.00765	1.01070	1.00543	1.01293
1961-92	1.00616	1.00616	1.00000	1.00636	0.99981	1.00597	1.00019

Table 5, continued

Explanations:

$R_{t,t-1}$:	index of technological change
$S_{t,t-1}$:	secular component of technological change
$U_{t,t-1}$:	unexplained component of technological change.